Changing by degrees - the impacts of climate change in the North West of England

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Changing by Degrees

The Impacts of Climate Change in the North West of England

Technical Overview

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Contents

A Report Prepared for the 'Climate Change in the North West' Group

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Context

This study is the first regional integrated assessment of the impacts of climate change for the UK. The methodology employed combines expert judgement, stakeholder assessment, qualitative and quantitative scenario construction and assessment methods, and literature review. The report focuses upon how the climate in the past, present and future has and will influence socio-economic practices, industry, and business affairs, land management and social life in the North West region. Integrated assessment involves capturing the impacts, adaptations and responses to climate change and the interactions between different economic sectors and the natural environment.

We investigated the impacts upon five 'landscape domains' (coastal zone, rural lowlands, rural uplands, urban fringe and urban core) and upon key economic sectors in the region through assessment of scientific findings and through interviews with stakeholders. The landscape domains are a geographically-based framework for bringing together the physical, biological and socio-economic character of the land.

We spoke to 148 individuals from 65 companies and 52 public sector agencies, policy and research organisations based in the North West. Their positive and enthusiastic response to the study is gratefully acknowledged and in itself tells us that there is a great deal of interest in the impacts of, and responses to, climate change in the North West of England. Areas of knowledge required for further policy development are presented at the end of the report.

Summary of Impacts

How has the climate of the North West changed, and how might it change further in the next century? The North West region has warmed by nearly 0.5°C in the last century. At Manchester Airport, for example, warming has been taking place since the 1960s onwards, with nearly 0.5°C in the last decade alone. Summer rainfall has decreased by up to 20% in the North West over the last century. Sea levels have risen, for example by 1cm per decade at Liverpool in the last century.

We are *certain* that the climate in the North West will continue to change over the next 100 years

It is *highly likely* that the climate will change due to the activities of humans on a global scale (namely emissions of carbon dioxide from burning fossil fuels, and of methane and nitrous oxide from agriculture, industry and waste disposal). Expert judgement suggests that climate change in the North West will result in increased temperatures, more winter rainfall, higher wind speeds, fewer winter frosts, perhaps more variable weather, higher sea-levels and perhaps more stormy weather and higher wave heights.

The climate changes already happening and projected into the next century will influence a great many physical, chemical, biological and human activities, ranging from the broad appearance of the landscape, coastline and urban infrastructure, to the success of economic sectors, and the pattern of individual and collective lifestyles. The precise impacts, however, will vary on a case-by-case basis depending on the sensitivity of the 'exposure unit' to the precise climatic change and upon other endogenous processes of change (economic, technical, social, policy, etc.). We are *reasonably confident* that the 'landscape domains' in the North West most sensitive to climate change till the 2080s will be the *uplands* and the *coastal zone*.

The Coast

The coastal zone will be subject to increasing risk of tidal inundation due to a likely increase in the probability of storm surges reaching dangerous levels in the Irish Sea. Much of the North West has a low-lying coastline which is already at risk from flooding. At least a third of the North West's coastline has 'hard' sea defence structures.

Major floods have been experienced over the last century, most recently in 1983, 1987 and 1990. Coastal and estuarine flooding can cause damage to buildings and infrastructure costing millions of pounds, whilst protection against flooding and erosion involves the construction of expensive defences (total costs expected to be some £20 million at Morecambe and £50 million at Blackpool for example). Climate change is likely to increase the risk of flooding by enhancing the combination of high tides, tidal surges and wave height. One estimate is that a rise in sea level of 15cm (likely to be achieved before the middle of the next century) will treble the probability of storm surges exceeding danger levels in the Irish Sea. Another estimate suggests that wave heights will increase by 2mm per year due to increased wind speeds resulting from climate change. As a first approximation climate change would double or perhaps even treble the probability of the Irish Sea reaching dangerous levels, though existing and planned flood defences would provide much protection. The design of flood defences in the North West is currently based on a 4mm/year rise in sea-levels due to climate change, but this does not take account of climate change-induced increases in wave height and in the frequency of tidal surges. Hence, the design life and current standard of protection of existing coastal defences is likely to be foreshortened by climate change.

The loss of mudflats and saltmarshes as the sea pushes up against hard defences would have a major impact on the internationally significant bird feeding grounds found in the extensive bays and estuaries of the North West. Some ports and harbours, coastal-based industries and occupations are also vulnerable to more extreme tidal events.

The mudflats and saltmarsh habitats of the Solway Firth, Morecambe Bay, Ribble, Mersey and Dee estuaries are particularly vulnerable to sea-level rise and storm surges and considerable areas of these could be lost. Similarly nationally important dune habitats along the Sefton to Southport coast are at risk, especially where opportunities for migration inland are restricted by coastal development ('coastal squeeze'). The dunes and saltmarshes are a valuable natural source of coastal defence and their loss will further exacerbate the threat to the coastline. Economic activities which are associated with the coastal zone are vulnerable to climate change: farming at coastal locations, fishing, coastal resorts, ports and especially the large amount of capital-intensive coastal-based industry in the North West. More dredging around harbours may be required as the silt brought down by rivers from the land changes in periods of drought (this cost one harbour in the North West £125,000 in extra dredging costs in a single year). Climate-change induced increases in south westerly wind speeds will drive more maritime silt into some harbours, again increasing dredging costs. Ship design will have to be adjusted to take account of higher average and exceptional wind speeds – if current levels of manoeuvrability and cargo safety are to be maintained. Off shore activities such as fishing, gas and oil field development and off-shore wind energy will be hindered by more storms and higher winds.

The high level of infrastructural development along the North Coast line significantly reduces the opportunties for 'managed retreat', although there are some candidate areas. Development significantly increases the ecological and socio-economic costs of coastal flooding in the North West.

Climate Change Summary for the North West (relative to 1961 – 90 mean)

Parameter	Scale	2020	2050	2080	Comments
Temperature	NW	+0.5 to +1.2 °C	+0.8 to +2.0 °C	+1.0 to +2.8 °C	Rise of about 0.1 to 0.3 °C per decade in line with global mean.
Precipitation	NW Summer	0 to +2%	-2 to -10%	-4 to -7%	The North West will generally become wetter in winter but may become drier in summer. Flooding may become more frequent.
	NW Winter	+5 to +12%	+6 to +13%	+7 to +21%	
Potential Evaporation	NW summer	+5%	+10%	+10%	Expected to increase over most of the country, with greatest increases in the South East.
River Flows	NW North		+5 to +15%		Seasonally, river flows in the North West would increase in winter and show little difference in summer.
	NW South		-5 to +5%		
Sea Level	NW	+7 to +38cm	+12 to +67cm	+18 to +99cm	The UK land mass is still recovering from the disturbance of the last Ice Age, and the North West is rising, lessening the impact of higher sea levels.
Wind Speed	NW Summer	-1%	0%	+1%	Increase in average wind speeds implies more frequent gales.
	NW Winter	+3%	+3%	+6%	
Extreme Events	Such as storms, tidal surges and hot summers are likely to occur more frequently				

Source: UKCIP (1998) & Environment Agency (1998)

The Uplands

The uplands could change significantly in character as soils, moorland vegetation and land uses adjust to warmer and wetter conditions.

There is a high degree of specialisation of upland plant and animal communities to a relatively cold maritime climate. Even a modest warming has the potential to produce far-reaching changes in many of these niche habitats. Loss of individual plants and animals from throughout the region is likely (without proactive management) including three rare Arctic fish - the Vendace, Shelley and Arctic Charr - from lakes in Cumbria, but there will also be inward migration of new species. Ecologists have already recorded new butterflies in the region due to warmer temperatures (the Speckled Wood and Comma for example). The risk of upland fires will increase and such fires can cost tens of thousands of pounds to tackle (e.g. £70,000 for one recent fire in the Peak District). Fires not only damage the economy of upland estates and their ecological value (sometimes irreversibly) but effect water quality through soot washout into streams and reservoirs. Fires also increase the amount of carbon dioxide emitted into the atmosphere, so acting as a 'positive feedback' (increasing global warming yet further). The decline in frost periods and in snowfall will change the ecology and public perception of the upland landscapes of northern England. Pests of vegetation, birds and other animals will increase due to warmer winters (as possibly already seen with heather beetle and caterpillar infestations in 1998).

Water Supply & Demand

Climate change adds significantly to the uncertainty surrounding future levels of water supply and demand. Water shortages could result from extended periods of drought and more variability in the pattern and extent of rainfall in the North West. Changing rainfall patterns are of particular concern to the water industry. More severe and prolonged droughts would impact on water availability, even in the North West which is traditionally seen as having high rainfall. The 1995/6 drought was one of the most severe on record and, with higher temperatures leading to record customer demand, was the most critical period for water resources in the North West in modern times. Reservoir stocks declined to record low levels - less than 10% at Haweswater and Thirlmere in the Lake District. Some Pennine reservoirs were actually emptied. Hosepipe bans and other restrictions were brought in, and drought orders obtained to enable additional abstraction for supply. The additional pumping cost amounted to several million pounds. Additional winter rain in the future will add pressure to the existing waste water and sewage treatment facilities, increasing the risk of overflowing.

Insurance

Much property in the North West is vulnerable to coastal and river flooding. The costs to the insurance industry arising from extreme flooding and storm events are potentially massive. Hence the insurance sector is vulnerable to a climate-change induced increase in storminess and flooding.
Insurance companies have underwritten present policies on the basis of weather patterns experienced over the last several decades. The risks of flooding and storms may well increase as a consequence of climate change, however. The insurance companies would then be over-exposed to the risk and may consequently suffer large economic losses. One insurance company operating in the North West has estimated that it has an exposure of £192 million to flooding in areas which can be defined as being at 'high risk'. The total exposure of all insurance companies operating in the North West is likely to be many times greater.

Industry

Summer working conditions will deteriorate as summer temperatures soar into the high 20s centigrade (mid-80s fahrenheit) more frequently. Productivity will decline and there will be knock-on heath and safety impacts.
We are *reasonably confident* that overall there will be medium-scale or minor negative economic impacts to many economic sectors, including **manufacturing** (working conditions, water management), **chemical industry** and **food processing** (cooling, flood risk and water quality), **electricity distribution**, and the **construction industry**. In conducting this assessment, we have assumed that managers in these sectors will respond through adjustment and adaptation to climate change, hence will reduce the *prima facie* impacts. Such adjustments are likely to require expenditure which will vary from a few hundred pounds to hundreds of thousands of pounds for the largest chemical plants in the region. It is likely that the adjustment to changed climatic conditions can occur within the usual time scale for replacement of plant and equipment (typically 10-40 years), but only if managers are aware that the climate is changing. Some sectors are only just waking up to the changed climate: architects and building designers are still designing buildings to function in the considerably cooler climate of the 1960s and 1970s, for instance, which could have important implications for working conditions and work-related stress as we enter the next century. Many factories and office blocks in hot summers already suffer from disruption to work and production due to uncomfortably hot working conditions, with attendant impacts on workers' health and productivity.

Sectors Benefiiting

Tourism, recreation and agriculture are amongst those sectors which may stand to benefit from the predicted climate change. It is our judgement that there are potential benefits resulting from climate change in some economic sectors, especially tourism and recreation and agriculture, but we can be less certain about the scale of such benefits and they are likely to be distributed unevenly across those sectors. Warmer winter weather will also reduce the number of deaths of older people, and will reduce disruption to the transport system.

Tourism and recreation may benefit from hotter, perhaps drier summers, especially if 'traditional' holiday destinations on the Mediterranean become uncomfortably hot. There will be a wider range of **agricultural** options in the North West due to climate change: new crops (e.g. apples) and varieties will become viable, some of which will be high value-added, though the soil quality will limit the agricultural activity in much of the North West. Nevertheless we may see new and highly productive agricultural activity emerging in specific locations. Agriculture will also enjoy a longer and more productive growing season, reducing the amount of feed that needs to be brought in and improving productivity, positive benefits of climate change which were identified by the farmers we interviewed. On the down side, however, more winter rain will challenge the adequacy of current farm waste water management systems, increasing the risk of pollution, and reducing the time that livestock can be put out to land. **Forestry**

is likely to do better in the North West provided that soil water and other essential plant nutrients are plentiful: some tree species will respond favourably to higher temperatures, longer growing seasons, increased CO_2 levels and nitrogen deposition.

Hotter, drier summers are likely to result in changes in **lifestyle**, particularly more outdoor activities, with attendant commercial and social benefits. At the same time, urban 'heat islands' will become more commonplace and unpleasant (and possibly dangerous) for those who live and work in urban areas. Those who are currently socially excluded, and those who live in isolated rural locations, are likely to be the most adversely affected by climate change. Taken-for-granted public and private services, such as coastal defence, flood defences, water treatment, environmental and emergency services, are likely to come under greater stress and may become less reliable (something which will affect all of us). **Street trees** will suffer from higher summer temperatures and water deficit: more suitable street tree species will need to be planted in future. The implications of climate change for **health** are likely to be mixed, with benefits from warmer winters (reduced mortality), better diets, more outdoor lifestyles, but also disadvantages from the impact of higher summer air temperatures on air pollution, heat stress, food poisoning and communicable diseases.

Perceptions of the North West Public

The public have expressed their concern about climate change and are looking for leadership in responding to climate change from policy makers. Responding to climate change offers up many opportunities for improving our way of life in the North West and for enhancing our economic performance in a sustainable way.

Detailed research on the perceptions of the public in the North West clearly demonstrates that there is public interest in, and concern about, the issue of climate change and a popular mandate for a policy response. The research shows that the public are looking to the policy community for leadership in responding to the issue of climate change. Policies to limit greenhouse gas emissions will improve the efficiency and productivity of energy use, with both economic and environmental benefits. There will be major new opportunities for the development of renewable energy technologies such as solar power, wind power (on- and off-shore), combined heat and power, bio-mass, hydropower, bio-gas, and so on. Climate change will open up major new global markets for clean technologies (machines and equipment, processes, products and 'know-how'), providing significant business opportunities for the North West's manufacturing industry. Climate change provides the opportunity for all sectors to re-organise their operations and to develop greater capacity for forward thinking (e.g. in the following sectors: forestry, transport, lifestyles, building design, air quality, urban development, tourism and provision of leisure). Indeed, one economic modelling study of the North West has shown that a package of policies to reduce greenhouse gas emissions would have a net benefit on employment in the region, with marginal economic effects.

Climate change provides a further reason to re-organise industrial, commercial and public operations in a sustainable way. Some of the policies will take several decades to have their full effect. This is appropriate given that the climate is likely to go on changing well outside of its natural range over the next century (and longer if no major reductions in greenhouse gas emissions occur at the global scale). It is not possible to assume that the impacts we have identified here for the 2050s and 2080s will be the same as the impacts in, say, the 2150s. The pace of climate change is likely to accelerate beyond the next century. The threat of the climate system responding in an unpredictable and chaotic fashion to continued human influences will commensurately increase.

Policies and Behaviours

We need to act now to set in motion the long-term changes that are needed to respond to climate change impacts and to reduce greenhouse gas emissions.

Many of the responses to climate change by the public and private sector will be incremental steps taken in response to both gradual change and extreme events. Extreme events will, however, sometimes induce a radical change in policy and behaviour, as illustrated by the response to coastal flooding events in the North West over the past 40 years. Policy measures which enhance the resilience of, and/or reduce stress upon, vulnerable landscape domains and economic sectors will be necessary in order that the extra impacts presented by climate change can be accommodated and do not serve to 'tip the balance'. Given that landscapes and economic sectors are not static, however, the challenge of managing change to conserve or improve valued assets will be brought into focus and enhanced by climate change. Policy makers need to become more aware of potential future climate change impacts in making decisions about resource management and public policy. Policy making across and within landscape domains and sectors will have to incorporate what we term '**climate headroom'** – that is inclusion of an extra margin of safety in decision-making to account for a change in the climate. There will be critical 'branching points' in future decision making where climate change considerations could favour one decision route rather than another, but only if climate change is on the policy agenda.

Summary of Regional Climate Change in the North West

What Has Happened to the Climate of the North West in the Last 100 Years?

- The 'Central England' Temperature record (which is representative of much of the North West region) shows an increase of 0.7°C from 1659 to 1995, 0.5°C of which represents warming in the 20th century.
- Mean temperatures at Manchester Airport for 1988-1997 have been 0.45°C warmer than the 1961-1990 average (an increase of 2.65°C if that rate of change continued for a century). Annual mean temperature has been rising at this site since the 1960s (the record extending from 1947-1997).
- In the North West, 30 year annual rainfall totals can vary naturally by up to plus or minus 5%. Winter or summer totals vary by as much as plus or minus 15%. These levels of *natural variability* may pose as great a challenge to water management in the region as is presented by human-induced changes, at least in the next few decades. A record of region wide rainfall since 1873 shows that annual rainfall displays no long term trend, whilst summer rainfall has fallen by up to 20%. An even longer-term record of annual rainfall exists for the Manchester area, dating back to 1786. The record shows several drought periods over the past 200 years (e.g. in the early 19th C and in the 1880s to early 1900s), which are of the same order of magnitude as the 1995/6 drought. The Manchester record, however, is not representative of nearby areas in the Pennines (e.g. Oldham) which suffered a relatively much greater reduction in rainfall in 1995/6.
- Increases in high intensity rainfall have occurred in the North West for the 1961-1995 period but only in the winter.
- A long-term record at Liverpool for sea-level change for the last 100 years indicates an increase of 13.9 cm/century from 1990. Allowing for land subsidence of 1.8cm/century, this gives an increase of 12.1 cm/century, i.e. just over 1mm per year.

What Might Happen to the Climate of the North West in the Next Century?

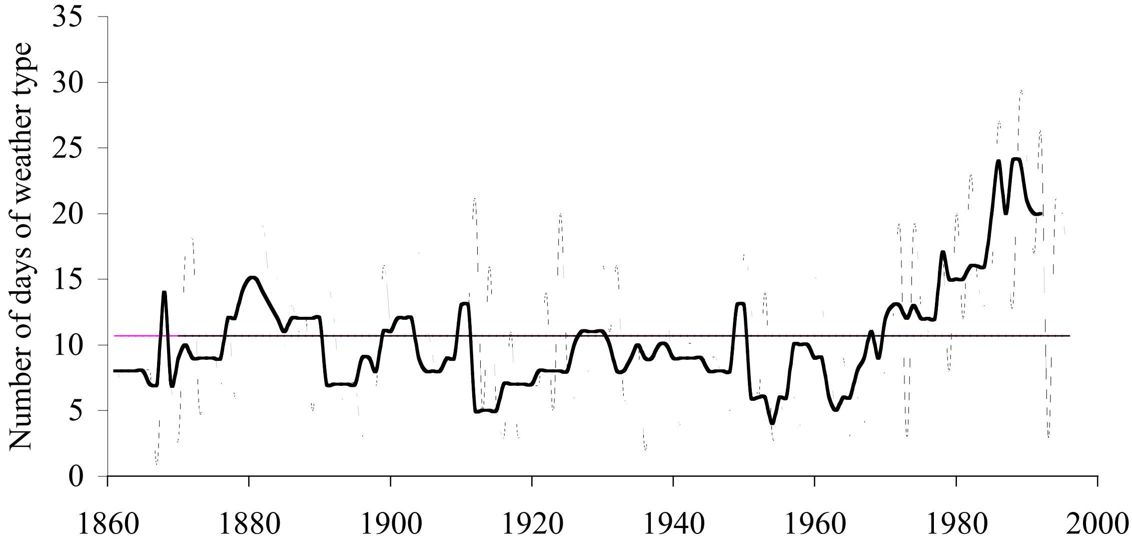
The UK Climate Impacts Programme (UKCIP) has generated a set of scenarios of possible future climate change for the years 2020s, 2050s and 2080s. Four scenarios for each time period are provided, which assume a low, a medium-low, medium-high and high sensitivity to greenhouse gas emissions (reflecting uncertainty in scientific knowledge of the response of the climate system).

- The rate of future warming in the North West varies from 0.9°C per century for the Low UKCIP scenario to 2.6°C per century for the High UKCIP scenario.
- Annual rainfall increases in all four UKCIP scenarios, by between 3 and 5%, but this is made up of rainfall increases in autumn and winter, decreases in summer and little change in spring. Winter rainfall increases over North West England by between 6 and 14% by the 2050s, whilst summer rainfall decreases by between 1 and 10% during the same period (cf. to 1961-1990).
- In terms of temperature, the summer of 1995 in the North West equates to the average summer to be expected by the 2050s under the UKCIP Medium-High scenario (i.e. 5 summers in the 2050s will be *hotter* than 1995).
- An extreme summer in the 2050s would be 4.7°C higher than the 1961-1990 average.
- The winters of 2050s will be at least as mild as the mild winter of 1989/90, but some winters in the 2050s will be much milder, e.g. 3.5°C warmer than the 1961-1990 average.
- The rainfall in the extreme years of the 2050s will not be any more extreme than the current extreme years, e.g. winter 1989/90 and summer 1995, though evaporation rates would be higher.
- UKCIP scenarios give a range of future sea-level rise of between 12 and 67cm by the 2050s with the Medium-High scenario giving 25cm. This is a rate of 31.2 cm/century, i.e. twice that currently observed for Liverpool.
- Daily Temperature Extremes: by the 2050s under the medium-high scenario, the number of degree days above 25°C can be expected to double for Manchester Airport, whilst degree days with minimum temperatures below freezing are reduced by about 65%.
- A hot summer in the North West (comparable to 1997) is 10 times more likely to occur by the 2020s and 20 times more likely by the 2050s.
- The chance that summer precipitation will be less than 50% of the average will double by the 2020s and double yet again by the 2050s.

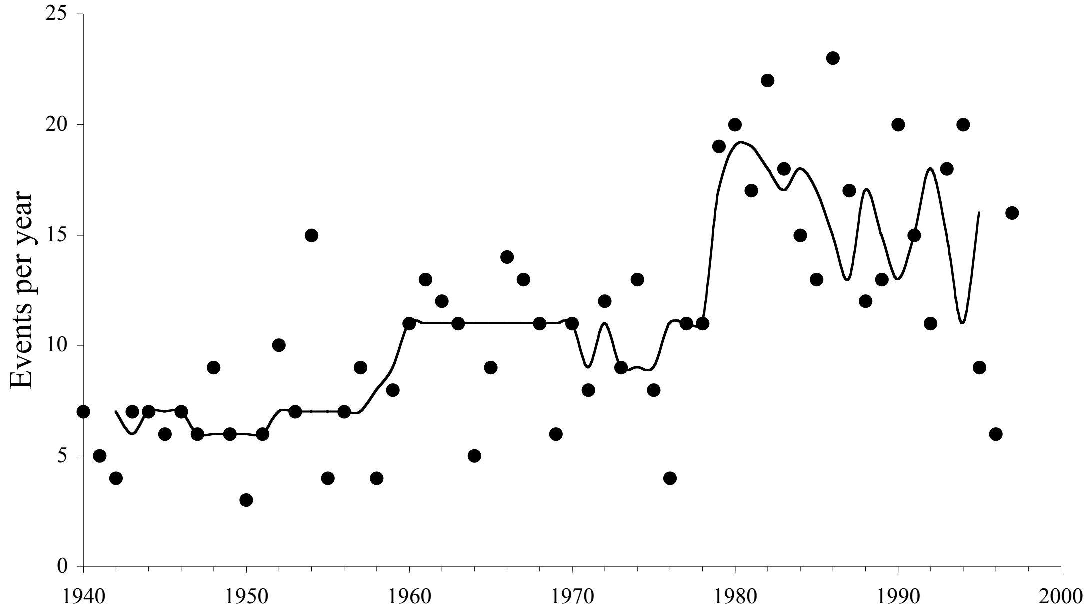
Surprises

Collapse of the Thermohaline Circulation is unlikely, as is the collapse of the West Antarctic Ice Sheet. (The thermohaline circulation is a massive circulation of water in the world's oceans which brings considerable amounts of heat to western Europe, raising average temperatures by some 5-10°C than their latitude would imply. The Gulf Stream is the best known element of the circulation). Collapse of the thermohaline circulation is unlikely, but it would have major consequences for the climate and for society. This is because it could result in significant cooling in North West England (and North West Europe more generally) even whilst most of the world warms up. Collapse of the West Antarctic Ice Sheet is also unlikely, but again would have major impacts, in this case raising sea-levels yet further.

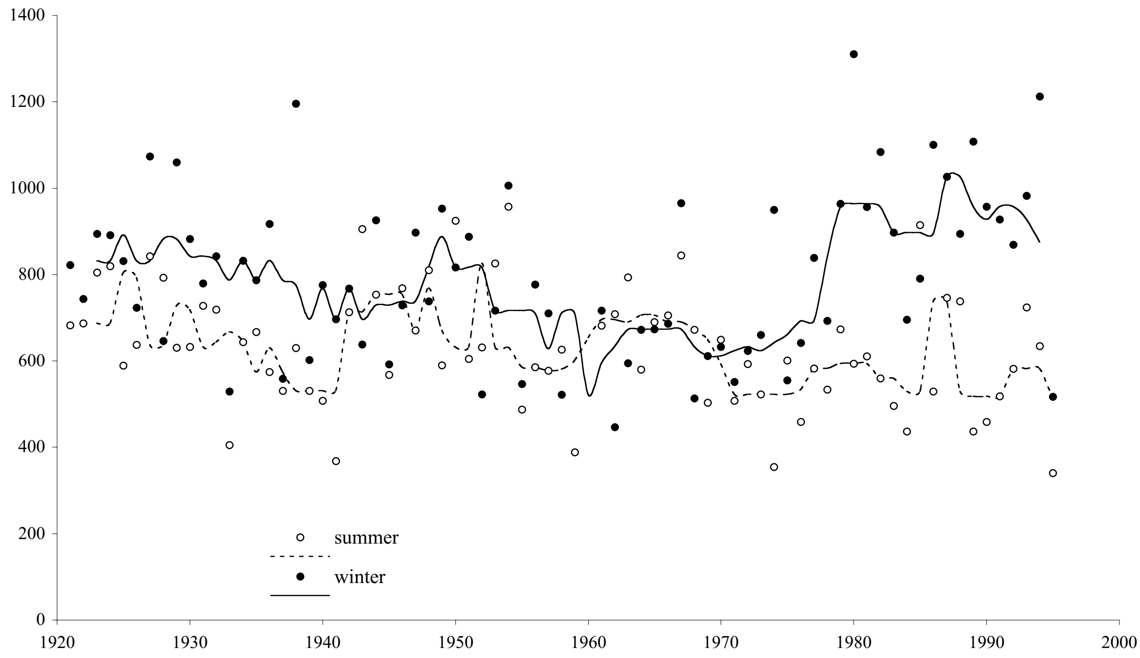
Occurence of South Westerly Weather Types (source: H. Orr, pers.comm.)



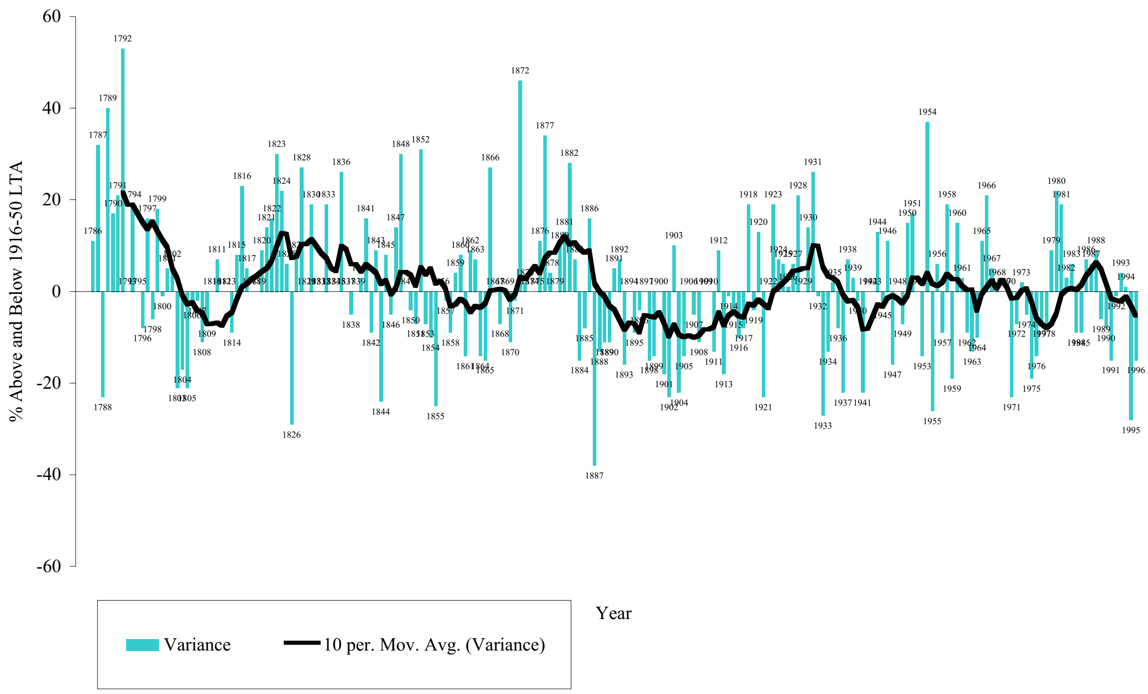
Intermediate Flood Frequency at Halton/Caton 1940 - 1997 (> 230m^3s^{-1}) (source: H. Orr, pers.comm.)



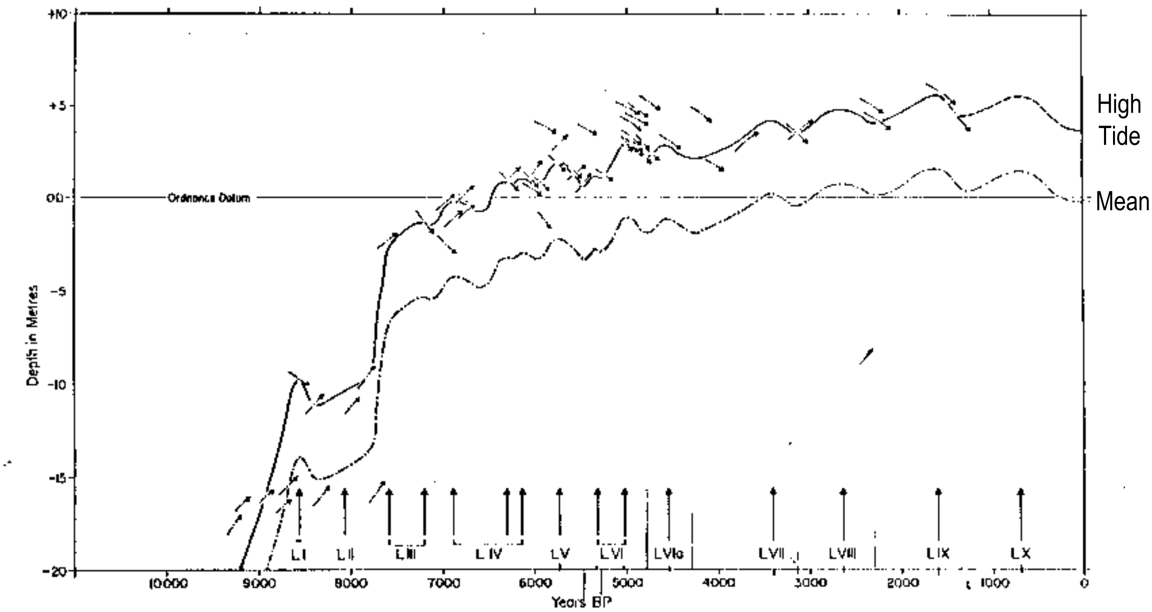
Summer and Winter Rainfall at Sedburgh (source: H. Orr, pers.comm.)



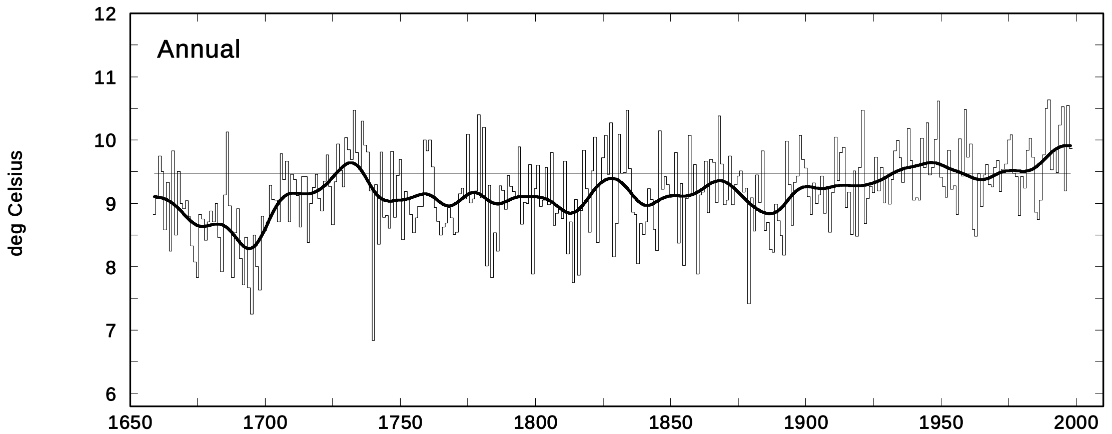
Variation from Long Term Average Rainfall for the Manchester Area 1786 - 1996
(source: Environment Agency, pers.comm.)



Relative Sea Level Changes in North West England from 9200 - 0 years B.P
(source: M. Tooley, 1976)

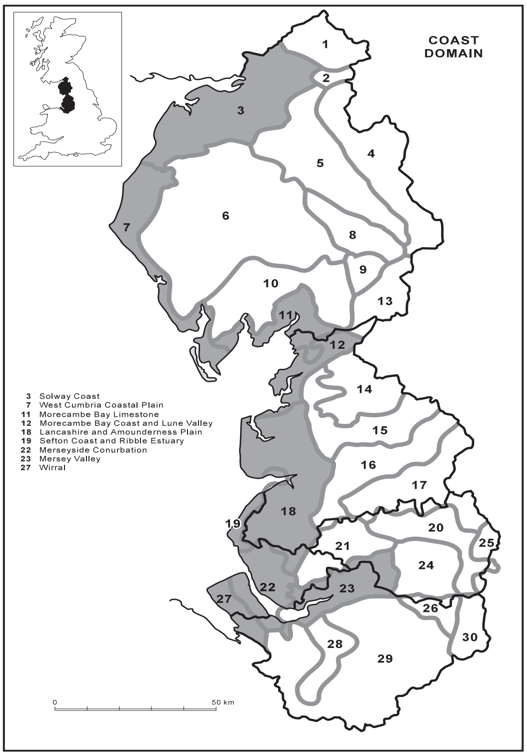


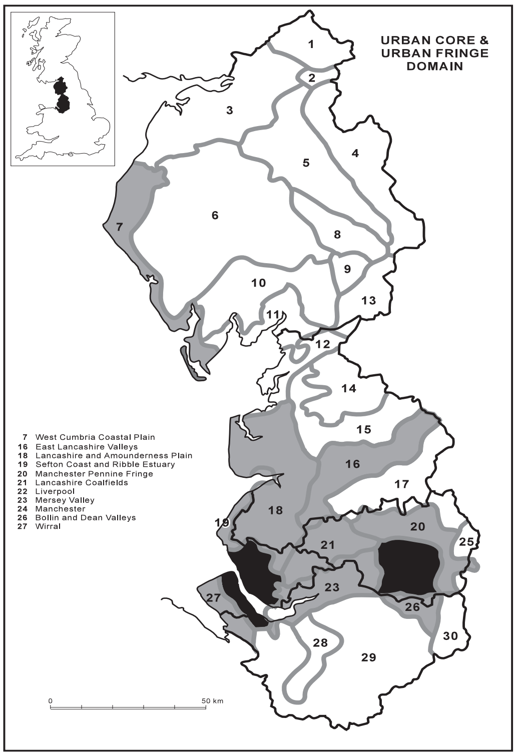
Annual Mean Temperatures for Central England, 1659 - 1995 (source: Hulme & Barrow, 1997)

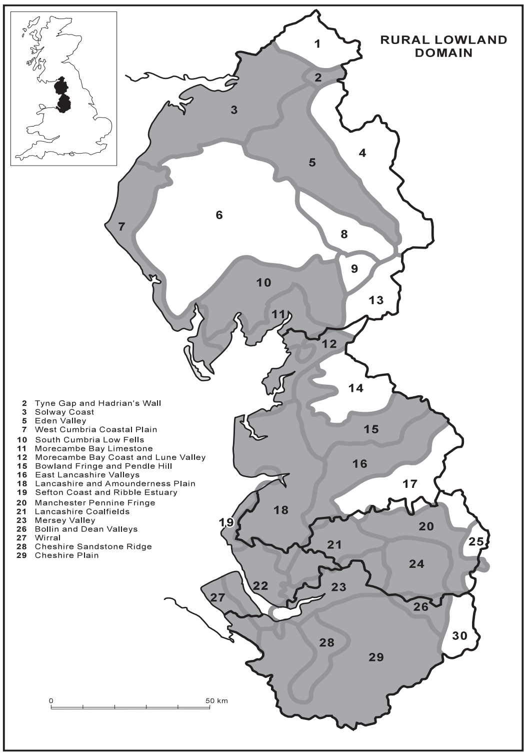


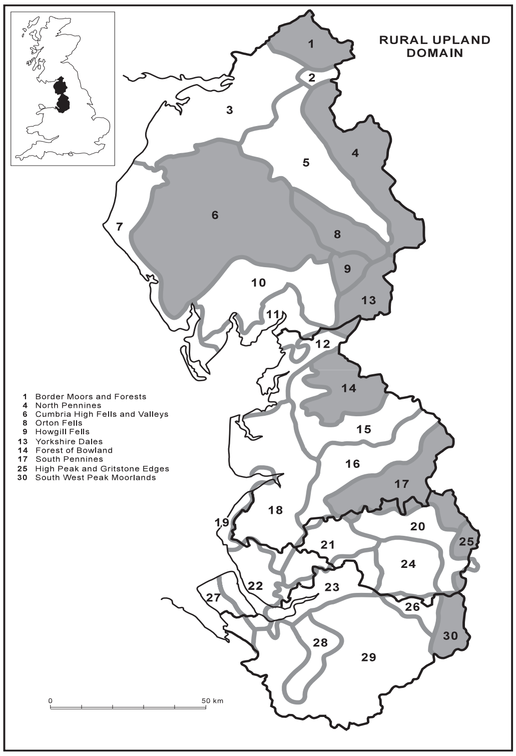
Climate Change Sensitivities

The following tables aim to summarise the likely impacts of climate change in the North West according to our best judgement. The tables do not present predictions, but likely sensitivities given the climate change scenarios presented by the UK Climate Impacts Programme. We have decided whether the impacts are 'beneficial' or 'detrimental' by asking what will be the effects of climate change upon: a) ecosystems and b) current and likely future infrastructure and business activities (using the assumption that 'business as usual' happens in the next 20-80 years). The decision to define the impacts as beneficial or detrimental is inevitably a subjective judgement, but does reflect a consensus amongst the members (stakeholders and scientists) of the Climate Change in the North West Group.









Responses of the Landscape Domains

Landscape Domain	Likely Sensitivities & Effects		Comments
	Beneficial	**Detrimental**	
Urban Core & Urban Fringe	➢ More outdoor activities (community life, 'café society', etc.) ➢ Healthier lifestyles ➢ More active population, (walking, cycling, etc.) ➢ Economic benefits for the leisure industry ➢ Greater potential for community forests (temperature, growing season, CO_2 concentration, policy measures to off-set emissions) ➢ Lower winter heating bills ➢ Lower mortality from cold winters ➢	➢ Water shortages for garden irrigation ➢ Stresses on parks and gardens in their traditional form and on street trees ➢ Increased risk of food poisoning ➢ Heat island effect: unpleasantly hot micro-climatic conditions in homes, workplaces, retail and recreational areas ➢ Health risks through sunburn; greater air pollution from sunlight, temperature and inversion effects (e.g. PM_{10}s, SO_2, O_3) ➢ Structural damage from storms to buildings and other infrastructure ➢ Additional stress for remnant semi-natural habitats ➢ Flood risk from streams, rivers and sewers ➢ Increased uptake of air conditioning, increasing energy costs ➢ Rise of water tables upwards in industrial areas accelerated	Dependent upon other socio-economic and environmental factors, e.g. 'greying' of the population, greater mobility, higher disposable income, new households, and shifts in lifestyles. Reduction in disposable income also possible, however. This would reduce the potential benefits of climate change resulting from more cultural-based recreation.
Coast	➢ Opportunities for coastal zone regeneration (including nature conservation) ➢ Higher incomes from tourism ➢ Expansion of more temperature and moisture dependent species, e.g. blanket bogs, beech trees, reptiles and insects	➢ Higher sea water flood risk ➢ Intermittent or permanent loss of land ➢ Expenditure on coastal defences (with attendant loss of amenity value and biodiversity) ➢ More unpredictable coastal dynamics e.g. beach erosion ➢ Habitat loss (particularly salt marshes and mudflats) ➢ Loss of distinct temperate maritime coastal ecosystems ➢ Change in dilution and dispersal of effluents discharged to sea (industrial, sewage, power station, etc.)	Significant pressures already along the coastal zone include natural erosion, development pressures and tourism. Managed retreat is a serious policy option, but will be controversial. Its applicability in the North West is limited by the high level of development.
Rural Uplands	➢ Migration of new species ➢ Enhanced vegetation growth due to higher temperatures and longer growing season ➢ New opportunities for farmers and landowners, e.g. extended stocking of land, higher productivity of grasslands ➢ Greater recreational opportunities and associated economic benefits (e.g. outdoor pursuits) ➢ Possible accumulation of carbon in peat soils in wetter conditions with longer growing season ➢ Greater potential for upland forestry in right context	➢ Loss of niche habitats and species ➢ Erosion (localised and widespread), especially of peat soils ➢ More grazing opportunities on young shoots with detrimental effects upon vegetation. ➢ Potential for decreased vigour of vegetation due to water deficit ➢ Increased fire risk in dry springs / summers ➢ Increased risk of windthrow of forests ➢ Potential for shifting and more intensive patterns of agricultural cultivation with adverse ecological impacts ➢ Recreational pressures ➢ Impacts of new water supply / transfer options ➢ Low water flows / levels with impacts on biodiversity and water quality ➢ Increased 'flashiness' of streams and rivers, increasing flood risk and affecting biodiversity ➢ Possible release of carbon from peat soils due to decomposition	High dependence on agricultural policy, i.e. grazing pressures. Limited understanding of the complexities of the interactions between climate, land-use and ecosystems. In Cumbrian lakes, however, strong coupling between weather events (position of the Gulf Stream) and lake physics, chemistry and biology has been established. Whether upland peat soils will act as an enhanced source or sink of carbon is uncertain. Research is required to provide a clearer answer to that question.
Rural Lowland	➢ Farming opportunities e.g. new crops, more productive grasslands, longer stocking periods, better conditions for arable farming ➢ Recreational opportunities ➢ Migration of new species ➢ More rapid vegetation growth and longer growing season ➢ Many animals, birds and insects do better in warmer winters (including pests)	➢ Water supply problems, especially for potatoes, vegetables and currently irrigated farming ➢ Vegetation change; competitive species will out grow species with a greater conservation value ➢ Stresses on particular plant and animal communities e.g. ponds, meres (from algal blooms for example) and trees (e.g. beech) on light and clay soils ➢ Species migration limited by extent of development ➢ Stream, river and sewer outlet flood risk ➢ More cracking of land and higher soil moisture contents over winter, increasing risk of pollution runoff ➢ Farm waste water systems not designed to cope with increased rainfall, especially given possibly reduced period for disposal of manure on land ➢ Animal husbandry (heat stresses on animals) ➢ Adverse effects on aquaculture ➢ Water logged soils more susceptible to damage from cattle and farm equipment, limiting time available for working / grazing.	Heavily modified semi-natural ecosystems already severely impoverished. Climate change likely to be an additional stress, especially for species unable to adapt or migrate relatively quickly. Low connectivity between present habitats will prevent migration of species, reducing their ability to adapt to climate change.

Summary of Likely Sensitivities and Effects of Climate Change by Economic Sector

Sector	Likely Sensitivities & Effects		Comments
	Beneficial	**Detrimental**	
Chemicals	➢ Better storage conditions ➢ Less freezing ➢ Expanded and new markets (e.g. for soaps) ➢ Plant re-design opportunities	➢ More cooling (increased capital and running costs) ➢ Water management (abstraction; quality of incoming water due to low flows / turbulence; treatment of waste water, with high winter rainfall threatening to exceed capacity of treatment facilities and, in summer, low flows reducing permissible discharges). ➢ Flooding & storm risk ➢ Loss of markets (e.g. for anti-freeze agents) ➢ Increased volatility of certain chemicals at higher temperatures	Highly dependent upon economic markets
Other Manufacturing	➢ Lower running costs (less energy for winter heating) ➢ Expanded and new markets (e.g. renewable energy and off shore support infrastructure; drinks and foods typically preferred in hotter weather, etc.)	➢ Working conditions ➢ Potential increase in energy demand for cooling ➢ Flood & storm risk ➢ Waste water management issues (as above)	Incremental adaptive response to gradual changes and/or extreme events likely. Reality of changes for operations will have to be demonstrated to induce change.
Buildings	➢ Lower heating bills in winter ➢ New design opportunities with attendant economic savings on heating, water and maintenance bills ➢ Less disruption from cold weather during construction process, though with the possibility of water logged lands limiting available window for construction work	➢ Working & living conditions adversely affected by summer heat ➢ Higher energy use for summer cooling ➢ Flood & storm risk ➢ Increased maintenance (due to storms, etc.) and possible adaptive measures required ➢ Historic buildings / artefacts vulnerable ➢ Running costs (e.g. insurance) ➢ Subsidence on clay soils ➢ Effects of sunlight on materials (e.g. impact of UV on plastics / textiles).	Statutory building standards below most other EU countries. There are early signs of a change in perception of resource use in buildings.
Energy	➢ New markets/technologies ➢ Opportunities for non fossil fuel energy sources, e.g. renewable sources such as biogas, wind, solar power, biomass, combined heat and power, etc. ➢ Opportunities for energy efficiency and conservation, bringing new jobs	➢ Flood & storm risk and effect on electricity distribution ➢ Overheating of undergound cables ➢ Small hydropower affected by reduced summer rainfall ➢ Increased storminess could require design change in wind turbines	Energy efficiency policy important (e.g. 'Standards of Performance' programme). Early signs of a shift in how energy as a resource is viewed.
Tourism & Leisure	➢ Expanded markets ➢ New markets ➢ Benefits to other sectors through indirect 'multiplier'	➢ Variability of weather ➢ Flood & storm risk ➢ Running costs of tourist facilities (e.g. insurance) ➢ Loss of amenity value from sea defences	Impacts will depend upon future socio-economic and cultural changes which are unknown.
Insurance	➢ New and expanded markets (flood and storm risk, new businesses, etc.) ➢ More sophisticated risk assessment methods and knowledge base ➢ Fewer claims due to burst pipes in cold winters	➢ Higher uncertainty ➢ Greater exposure to risk ➢ Market differentiation ➢ Possible future difficulty of obtaining insurance (and re-insurance) cover for some customers	More risk-based approaches emerging as scientific base expands. Future of 'equity' principle unclear.
Water	➢ Rationale for forward planning ➢ Leakage reduction and demand management favoured ➢ Water conservation / efficiency favoured ➢ Better catchment management ➢ Infrastructure for waste water and effluent treatment improved and capacity enhanced ➢ An expanded integrated network becomes more resilient to variability in rainfall	➢ Variability of supply ➢ Supply vulnerable to more frequent and severe droughts ➢ Increased uncertainty ➢ Potential investment needed to increase supply and transfer options ➢ Wastewater management (increased risk of overflow and 'foul flooding') ➢ Increased flood risk from rivers and streams, with negative effects on soils, river banks, habitats, biodiversity, housing, infrastructure, etc. ➢ Pressures upon habitats in the uplands affecting water quality in reservoirs ➢ Potential problem for non-mains water supplies. Prolonged summer dry season makes aquifers and surface sources non-viable. ➢ Vulnerability of areas of the region which are not part of the integrated water supply network. ➢ Greater problem of water colouration due to peat soil cracking and decomposition followed by intense rainfall events.	Role of government policy and long-term private sector investment critical, e.g. on leakage reduction, water conservation, moves towards metering and demand management, etc.
Transport	➢ More tourism increases demand for transportation ➢ Less disruption to winter travel due to cold and severe weather ➢ Demand for railway journeys and water-based transport increased (cruises on canals, rivers, lakes and sea, etc.) ➢ Some ports and harbours turned over to tourism / recreational purposes	➢ Some ports and harbours vulnerable to sea water flooding and to changing siltation patterns; requiring major infra-structural changes ➢ Increased risk of flooding of railway lines along coastlines without ameliorative actions ➢ Re-design of ships necessary in order to allow manoeuvring at high wind speeds ➢ Canals suffer from low water levels in summer without new supply options ➢ Roads and railways can be adversely affected by temperature (buckling, fires, melting of asphalt, etc.) ➢ Possibility of reduced payloads for aircraft	Some problems are responsive to adaptive measures. More intractible are those requiring large capital investment in pursuit of relatively marginal economic activities.
Cultural Heritage	➢ Greater use of outdoor resources (parks, gardens, historic sites, etc.). ➢ Greater income from recreational use ➢ Reduced cost of warming buildings in winter	➢ Temperature and light related stresses upon fragile artefacts – buildings, fabrics, paintings, furniture, etc. ➢ Increased costs of cooling buildings in summer ➢ Greater stress on popular recreational destinations – need for greater visitor management	'Conservation' does not imply 'standing still'. Many ecological and socio-economic systems are fluid and dynamic and need to be managed as such.
Public Policy	➢ Environmental awareness & resource use ➢ Integrative thinking & planning ➢ Organisational reform & partnerships ➢ Regional economic transformation	➢ Effect on publicly owned resources ➢ Taken-for-granted services (utilities, emergency services, etc.) may become less reliable ➢ Crisis management ➢ Climate change not currently incorporated into much decision-making	Local Agenda 21; Local Environmental Agency Plans; Shoreline Management Plans. Need for 'climate headroom' to be included in decision-making.

The Impacts of Climate Change: Degree of Sensitivity by Landscape Domain and Economic Sector

Domain/Sector	Year 2020s	2050s	2080s	Impact (-5 to +5) -ve	+ve
Coast	Medium	High	High	-4	+1
Urban Core/ Urban Fringe	Low	Medium	Medium/ High	-3	+3
Rural Lowland	Low	Medium	Medium	-2	+2
Rural Upland	Medium	High	High	-4	+2
Chemicals	Low	Low	Medium	-1	+1
Other Manufacturing	Low	Medium	Medium	-2	+1
Buildings	Low	Medium	Medium	-2	+1
Energy	Low	Low	Low/ Medium	-2	+2
Tourism/ Leisure	Low	Medium	Medium/ High	-2	+3
Insurance	Medium	Medium	Medium	-3	+1
Water	Medium/ High	High	High	-4	+1
Public Policy	Medium	Medium	Medium/ High	-1	+4
Transport	Low	Medium	Medium	-2	+1
Cultural Heritage	Low	Medium	Medium	-2	+2

Confidence levels:

- most confident
- moderately confident
- least confident

Assessing the Impacts of Climate Change in the North West of England

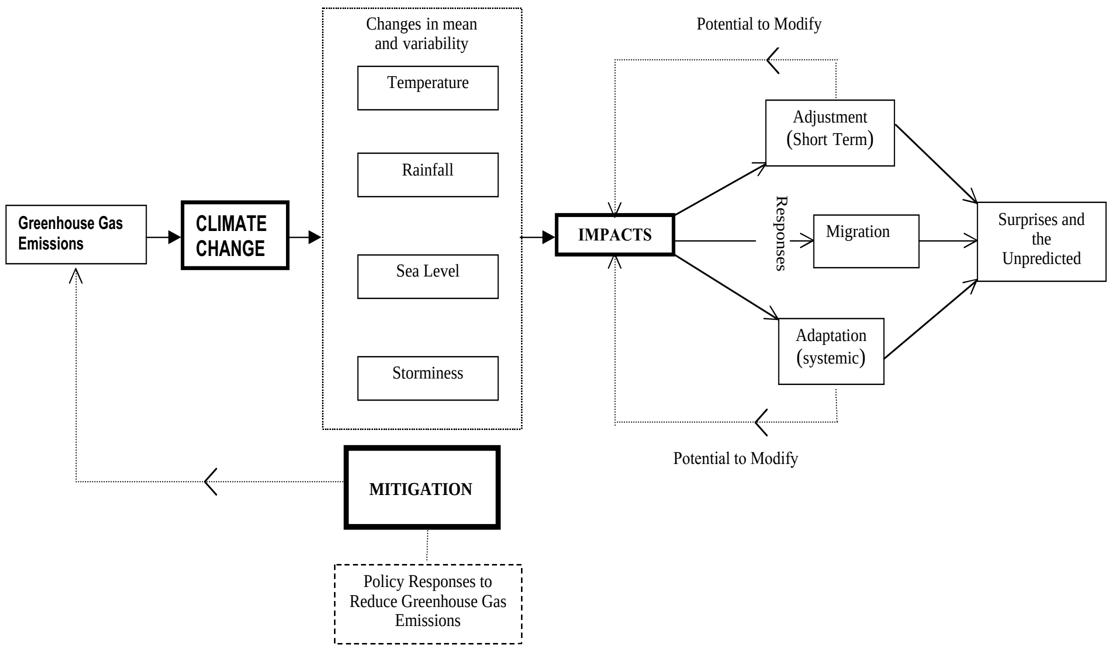
Greenhouse gases, in particular carbon dioxide from burning fossil fuels, methane and nitrous oxide from agriculture, other land-uses, industry and waste disposal, are causing climate change on a global scale. The climate is also changing in the North West of England. Climate change will be manifested through changes in meteorological variables, in particular: temperature, rainfall, humidity, wind speed, snowfall, frostiness, and weather-related variables such as the water content of soils and water loss from soils and vegetation due to evaporation, sea-level, tidal surge level and wave height. These changes in the long-term state of the weather will have multiple impacts.

Natural and human communities will have to respond to such changes. For example, plants and animals will have to adapt or migrate to regions which are more climatically suitable, at least if they have the opportunity to do so. Likewise humans will need to respond to changes in the weather: for example, farmers may adjust cropping or stocking practices; builders will adjust the design and construction of roofs, and temperature control systems; water resources will be conserved and new supply options may be required, insurance premiums will change, and so on. Adjustments and adaptations to climate change will reduce the impacts but will require the investment of resources and could themselves have unanticipated consequences (beneficial as well as adverse) (see Figure below).

Much of the public debate on climate change policy is concerned with the reduction of greenhouse gas emissions or ‘mitigation’. Such policy responses are distinct from adjustment or adaptation to climate change impacts. Adjustment / adaptation is a localised or regional response to a specific impact, whilst greenhouse gas mitigation is a response at the global-scale. Mitigation is a global response because greenhouse gases are rapidly mixed in the global atmosphere, so that the same quantity of emissions anywhere in the world contributes equally to global climate change and to regional and local climate change anywhere else. There is no automatic link between climate change impacts and greenhouse gas mitigation, though in some cases emissions will increase or decrease as a result of climate change impacts (this could happen, for example, through the possible release of carbon in upland soils at higher temperatures). We also suspect that some impacts (the loss of a rare and valued for example) will contribute to the policy argument for reduction of greenhouse gas emissions.

In exploring the potential impacts of climate change in the North West England region, we have considered the impacts upon natural resources and land management, the impacts upon commercial and business interests, and the implications for, and responses of, public policy.

Climate Change Impacts and Mitigation



Natural Resourses and Land Management

Lowland Ecology

The region's lowlands are dominated either by agriculture or urban uses; as such the 'natural' environment of plants and animals, and the soil, water and atmospheric systems which support them, is highly modified, often existing under conditions of stress or specialised adaptation. Nevertheless the North West does possess a valuable complex of lowland acid peat bogs, marshes and estuarine resources, the remnants of a once extensive system, and now protected by nature conservation designations. These highly specialised ecosystems are vulnerable to climate change through changes in rainfall regimes (especially summer drought). However, more winter rainfall could be beneficial, depending on the level of artificial drainage. Many plants and animals can in principle respond to climate change by migrating northwards or up hill in search of more suitable climates. The high level of development in the region means, however, that valued habitats and their plant and animal communities tend to survive in small pockets in the midst of urban areas or agricultural land and they will consequently find it difficult to migrate their way out of climate change.

Some key indicators of a changing climate are invertebrates. 'Southern' butterflies have been moving northwards since the early 1980s, e.g. Speckled Wood and Comma into Cumbria and the Small Skipper into south Lancashire. In the sheltered micro-climate of Morecambe Bay, the Grizzled Skipper and Duke of Burgundy butterflies have been doing well in the 1990s. The most endangered butterfly in the UK, the High Brown Fritillary, occurs around Morecambe Bay (one of only three populations nationally) and prefers hot dry weather. Dragonflies, such as Black Tail Skimmer, Emperor Dragonfly, Broad Bodied Chaser, Migrant Hawker and Ruddy Darter have moved into parts of the North West from the Midlands and South East. Reptiles such as the Great Crested Newt appear to be emerging earlier in the season due to the warmer winters. Similarly, there is evidence of earlier nesting, egg laying and hatching amongst birds, notably oyster catchers, wren, warblers and crows. The breeding cycle of many birds will occur earlier in the year in response to temperature and the availability of invertebrates for food. A higher frequency of invertebrates encourages over- wintering by summer visitors, and the northward migration of species (grebes being a notable example in the North West). The extent to which changes in the weather have contributed to these changes in species distributions needs to be considered carefully and on a case-by-case basis. Land management practices, deliberate introductions and deficiencies in monitoring all need to be considered as contributory factors in explaining the appearance of new species. Nevertheless, insects, reptiles and birds are important indicator species of climate change, and they are likely to experience considerable variation in their adaptive responses.

KEY MESSAGES

- Evidence exists already that climate change is influencing the breeding patterns and success and distribution of insects and birds, these potentially acting as good indicators of climate change.
- It is unclear whether lowland peat habitats will benefit or suffer from climate change.
- Some plant and animal species will be unable to migrate given their high degree of adaptation and the scarcity and low connectivity of lowland habitats.

….. AND QUESTIONS

- Can better methods be developed to explain and predict the influence of climate change on species distributions (as opposed to land management)?

Upland Ecology

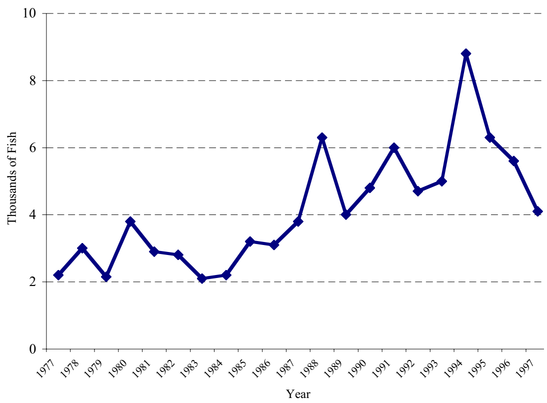
The uplands of the North West are a specialised ecological and land-management system. The temperature declines rapidly as one goes up hill (a decrease of 7°C per 1000m upwards). As a consequence, the uplands may be particularly sensitive to relatively modest changes in the climate. One analysis of the impacts of climate change in the uplands found, for example, that sub-marginal land (mainly in the high Pennines and Cumbrian fells) would decrease from approximately 25% of present upland land to just 9% with a 1°C warming. A 2°C warming would reduce sub-marginal land to 2% of the total uplands, and such land would disappear altogether with a 4°C warming. There would be an increase in potentially cultivatable land, though in practice soil types and the steep gradient of the land would greatly limit the upwards expansion of cultivation. The same analysis suggested that a warming of 1°C reduced upland frosts by a quarter, a 2°C warming reduced frosts by a half, and a 4°C warming led to an 80% decrease. Instead of experiencing 140 days of frost per year as at present, the highest uplands would only experience 29 days of frost per year. A 50 year record of temperature from two stations in the north Pennines has not illustrated any warming trend, but it is not possible to extrapolate from only two stations to a larger geographical area. Warming has occurred during the 1990s in the temperature record at Eskdalemuir (239m) in the Scottish Southern Uplands and more generally in that region. It is possible that local meteorological changes will moderate the response of the uplands to climate change in terms of temperature. A more detailed analysis of temperature records from meteorological stations in the UK above a given altitude would be a valuable contribution to our understanding and ability to conduct impact assessment.

The appearance and ecology of the uplands is, in large measure, determined by the dominant farming regime; principally sheep grazing. The highly specialised ecosystem of the uplands is vulnerable to change because of the marginal existence of many of its components. In particular, there are unique remnants of ice-age plant and animal communities on higher Cumbrian Fells and in some Cumbrian lakes and rivers (the Shelley, Vendace [*Coregonus Albula*] and Arctic Charr [*Salvelinns Alpinus*]. Arctic-Alpine plants at risk include: Mountain Avens, Alpine Lady's Mantle and various rare saxifrages and sedges. Some of the Cumbrian specimens are genetically distinct from populations elsewhere and may be genetically adapted to the climate conditions of the region, but the climate is due to change and at a rate which greatly exceeds evolutionary genetics. Habitats tend to be spatially related to one another in the uplands, however, hence the opportunities for northerly or upwards migration of species is more feasible than in the lowlands.

The interconnections between land-use, especially grazing pressures, climate change, erosion, drainage (gripping), run-off and ecological change, are all highly uncertain and of much interest at the present time. There has been an increase in the winter river flow of the River Lune over the past 80 years of 20-25%, and a decrease in the summer flow. There has also been a three to four fold increase in the frequency of medium-sized floods of the River Lune at the down stream villages of Caton & Halton over the last 40 years. Are such multi-decadal changes best explained by climate change or land-use change, or a combination of both? This question needs to be answered in order that the impacts of future climate change can be better understood in upland ecosystems, and the opportunities for reducing the pressures upon this ecosystem through other policy measures can be ascertained.

Lower river flows in summer, and more variability and extreme events, will have significant impacts on upland and lowland river biodiversity, including the loss of fish spawning sites. Increased 'flashiness' of streams and rivers can result in flooding down-stream with economic and social costs, and can increase rates of soil and river bank erosion. Impacts on salmon and trout populations due to higher water temperatures are unlikely to be important until a threshold of about a 4°C increase above present average water temperatures is reached, beyond which populations will suffer, although coarse fish populations are likely to prosper in the warmer conditions.

Declared Regional Salmon Catch by Rod in the North West



Source: Env. Agency (1998)

The uplands of the North West are characterised by an extensive heather moorland resource, demanding a distinctive management regime; climate change could make this more difficult. Heather tends to do better in somewhat drier conditions so may suffer from increased winter rainfalls, though heather can adapt to wetter conditions, especially if assisted by appropriate management practices. Earlier growth of heather in the season will increase the availability of young shoots to grazing animals, and excessive grazing could thereby interact with climate change with detrimental consequences. Excessive grazing produces short swards of vegetation such as *Festuca* / *Agrostis* on grassland slopes, which may be more vulnerable to climate change, especially under drought conditions.

One expert thought that warming with higher rainfall and lower atmospheric sulphur deposition would probably lead to an increase in blanket peats and bog mosses, as well as favouring species such as the currently marginal crowberry. Bell heather, which is currently temperature limited, might move upwards, whilst purple moor grass (*Molinia*) might also expand onto higher land. An increase in temperature would also create the conditions for the return of scrub oak, birch and willow, though their establishment will depend upon the extent of grazing pressures. Some plants which reach the limits of their northerly distribution in the low carboniferous hills of southern Cumbria might extend northwards, including Old Man's Beard, Black Bryony, Horseshoe Vetch, small-leaved lime and Squinancy-Wort. Several of these species might serve as indicators of long-term climate change, including the wooly hair moss.

Recent research indicates that drought is detrimental to both bracken (which covers 3% of the land cover in the North West, and 5.5% in Cumbria) and heather, but its effect on the balance between the two species depends on the timing of the drought. Early drought damaged bracken, whilst late droughts had more severe effects on heather. Overall, as in the lowlands, the existing semi-natural vegetation is likely to change as a result of increased growth of competitive species. This would have negative impacts on 'stress tolerator' species, including most of the plants of high conservation value. Some species will survive, however, because of their ability to survive at inaccessible locations such as cliffs. Drought is believed by many ecologists to be a more important driver of vegetation change than temperature rise or the so-called CO_2 fertilisation effect (the enhancement of plant growth due to higher CO_2 levels). One study of the impact of the 1995 drought in the south Pennines found that tap rooted forbs such as *Sanguisorba minor* and *Pimpinella saxifraga* had a clear competitve advantage over other plants. Drought seemed to act as a 'resetting mechanism', restricting the progress of plants which had expanded onto shallower soils from the deeper soils of the valley bottom.

Peat soils play an integral part in carbon storage; it is estimated, for example, that the upland peat bogs in the UK contain 200 times as much carbon as all UK vegetation. Soil organic matter accumulation, and peat formation, is favoured by cool, wet climates and water logged soils. Decomposition of peat soils increases with temperature, however, provided the soils retain sufficient moisture for the decomposer organisms to function. Production of plant biomass also increases with temperature and length of growing season, given adequate supplies of water and nutrients. It is clearly crucial that we are able to predict the impact of climate change on the balance between these two opposing processes. Recent studies in the Pennines have calculated rates of peat formation over the last several thousand years. The results indicate that wet periods have been times of rapid peat accumulation. The temperatures during these periods, however, cannot currently be reconstructed. It is therefore not possible to use such historical analogues as predictors of the impacts of climate change on peat growth over the next 100 years. Mathematical models of peat accumulation have been developed but give conflicting results on the impacts of climate change.

One research programme estimated that upland vegetation could absorb up to a third more carbon as a result of higher concentrations of CO_2 and higher temperatures. This study stated, however, that release of more CO_2 is likely in the long run due to higher temperature-dependent decomposition. A further factor to consider here is the role of rainfall in increasing peat soil erosion, especially when it is associated with strong winds; driving winter rains may well increase as a result of climate change. Land management has an impact upon soil carbon stores. Disturbance of soils, such as ploughing, leads to an increase in decomposition rates and increased outputs of CO_2. Drainage of soils, particularly peats and peaty-surfaced soils, has a similar impact. Burning of heather systems, as part of the management of grouse moors, seems to lead to a net reduction of carbon in the system (due to the loss from vegetation).

Methane (CH_4), another greenhouse gas, is emitted from soils, as well as industry (e.g. from the gas platforms in Morecambe Bay), landfill sites and animal wastes. Soil emissions are largest from wet and organic-rich soils, particularly wetland ecosystems (which produce 5% of the UK's methane emissions). A recent study in the North Pennines showed that increasing soil temperatures led to increased conversion of methane into CO_2. This is a 'negative feedback' since CO_2 is a less powerful greenhouse gas than methane. Increased rainfall is likely to reduce the conversion of methane into CO_2, however, and the net effect of the two opposing trends is not known. Drainage of land will tend to remove methane, but that benefit would be off set by increased decomposition of peat and thereby generation of CO_2.

Land management will continue to exert a significant influence upon the character of the uplands, and there are a range of possible ecological and landscape trajectories for the uplands which are management related, such as the re-establishment of woodland and even the extension of purple moor grass. Climate change will favour certain trajectories over others; for example those that aim to maintain vegetative cover by species which are reasonably moisture tolerant and do well at higher temperatures.

The number of grassland and heathland fires in the North West region (and nationally) shows a close correlation with dry and hot seasons (with the key meteorological variable being low rainfall rather than temperature). There was a very large increase in fires in 1995/6, especially in uplands located next to urban regions, reflecting the incidence of deliberate fires. The uplands are likely to be more vulnerable to accidental and deliberate fires as a result of future climate change. Reduced frosts and cold periods in the uplands will increase the incidence of pests and diseases. In 1998 there were extensive infestations of heather beetles and caterpillars in northern uplands which may well have been related to the exceptionally warm winter of 1997/8. Natural pests can cause serious destruction to vegetation and have a negative impact on upland biodiversity, farming and soils.

A remarkable correlation between the position of the Gulf Stream and plankton in Lake Windermere from 1965-1991 has been demonstrated. There is a strong negative correlation between the quantity of zooplankton in Lake Windermere in the summer and the north-south position of the Gulf Stream in the Atlantic Ocean. The position of the Gulf Stream influences the local weather patterns, which in turn influences the extent to which the lake becomes 'stratified' (separated into a warm water body above and a colder water body below) in early summer. The zooplankton respond to the lake stratification because it changes the availability of its food. The very close correlation between an oceanic phenomenon occurring thousands of miles away, and the success of micro-organisms in a lake in Cumbria, suggests just how sensitive some ecosystems are to weather and climatic patterns. It also suggests that lake monitoring may be a useful way of measuring regional climate change and its ecological impacts.

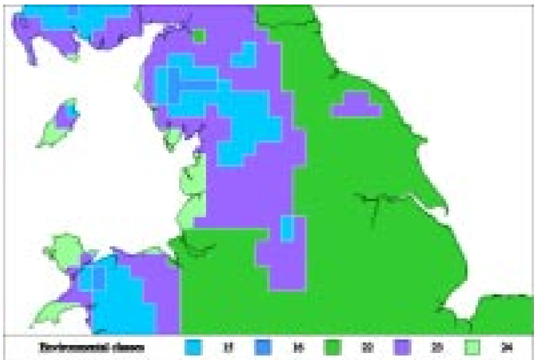
KEY MESSAGES

- The uplands are ecologically highly sensitive and some of the first effects of climate change are likely to be noted here.
- The role of upland peat soils and bogs in carbon storage is critical.
- Current land management practices for heather moorland are likely to come under stress, both through changing vegetation balances (such as bracken and heather) and through events such as fires.
- Long running records, such as that for upland lakes, can provide some notable indicators of regional climate change and its impacts.

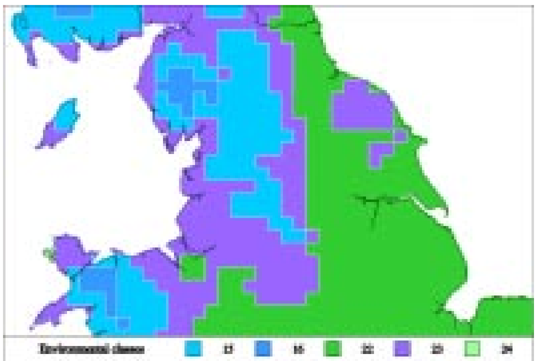
….. AND QUESTIONS

- Will climate change benefit peat soils in the uplands by increasing growth and accumulation of plant materials (as a result of higher temperatures and increased moisture)? Or will it have an adverse effect because the increased temperatures and erosion accelerate rates of decomposition of existing peat? (Despite much work on the subject, a definitive prediction of the impacts of climate change upon peats eludes us).
- What would be the impact of peat loss upon greenhouse gas emissions?
- Will heather benefit from hotter summers or be adversely affected by wetter soils?
- Will bracken benefit from climate change more than heather?
- Are increasing winter stream and river flows, and generally more flood events, explained by land-use or climate changes?
- Is the Lake Windermere record showing that the Gulf Stream influences the physics, chemistry and biology of lakes found in other water bodies?
- What is the increase in fire risk in the uplands due to climate change?
- How serious is the impact of warmer winters on upland pests?
- Which Arctic-Alpine species will survive in the area because of their location in extreme environments, such as cliffs? And which will be lost due to increased competition between plants?

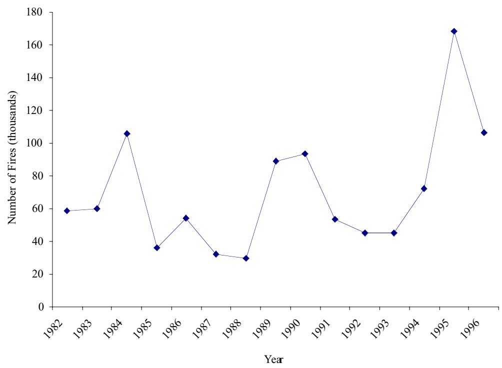
The European Environmental Classification at 10km square resolution showing the classes in northern England.



Modification of European Environmental Classification at 10km square resolution under the UK HI equilibrium scenario modelled to 2050 (source: M. Hornung, pers.comm.)



Grassland/Heathland fires (UK, 1982 - 1996)
(source: Home Office Statistical Bulletins, 1996, 1997, 1998)



County	Total Number of Grassland/Heathland Fires			Proportion of all Secondary Fires[1]		
	1994	1995	1996	1994	1995	1996
Cheshire	1,432	3,303	2,210	33%	50%	41%
Cumbria	394	656	843	27%	31%	35%
Lancashire	966	3,437	2,615	14%	36%	31%
Greater Manchester	3,294	11,795	5,399	19%	41%	27%
Merseyside	3,172	10,591	7,061	22%	43%	37%
England & Wales	60,608	150,818	90,186	29%	46%	37%

[1] Secondary fires are defined as those without casualties and requiring less than five appliances

sources: Home Office Statistical Bulletins (1996, 1997, 1998)

Agriculture

Agriculture in the North West displays a distinct upland/lowland division with an attendant diversity of farm types. Climate change is likely to bring about subtle changes to the existing patterns of agriculture through shifts in the type, range and viability of cropping and cultivation. Uses such as horticulture, for example, could expand with higher temperatures, though soil type is a limiting factor as is availability of water for irrigation. The North West has a lower investment in irrigation infrastructure than any other region of England. The horticultural industry near Preston and Ormskirk requires large amounts of water and there is already a restriction on abstraction by farmers from one of the aquifers because of over-abstraction and depletion of the resource. Farmers in such regions will probably have to invest in more on-farm water storage facilities, conserving excess surface water in the winter for summer use. We expect to see forage maize grown more widely in the North West region, due in part to climate change. The prospects of growing cereals would be enhanced if summer temperatures are higher and rainfall is lower, though soil types are a limiting factor. Weather conditions at harvesting periods are, however, less critical nowadays due to new harvesting technologies and new varieties. Fruit growing (such as apples) could become feasible in the North West in areas with better quality soils.

Higher temperatures and a longer growing season will generally increase the productivity of the grasslands provided that there is sufficient moisture in soils in the late summer and early autumn. Farmers in the North West will be able to produce a greater proportion of their own winter cattle feed, reducing costs incurred by bringing feed in and so enhancing profitability. Higher autumnal and winter rainfall would delay the release of stocks into fields in the spring and require earlier removal of stock. It would also reduce the period when soil conditions are suitable for the spreading of slurry and fertilisers with minimal risk of run-off. Guidelines exist for the spreading of slurry and animal manures and may have to be changed if rainfall patterns change. On-farm storage systems for slurry and silage are designed to cope with current levels of rainfall and may not be able to handle much larger volumes. Whilst more careful management of slurry applications and farm waste water systems will limit the negative impacts, the tendency for rainfall to be increasingly concentrated in intense events will make planning of these farm operations more difficult. Livestock farms are likely to have to increase their storage capacity for wastes and dirty waters, thus enabling them to store the waters until there is a suitable weather 'window' for spreading. The increased frequency of summer droughts will result in more frequent drying out and cracking of clay rich soils, with an associated increased possibility of rapid transport of pollutants to waters via the crack systems when heavy rainfall subsequently occurs.

Some soils are at risk from erosion due to stronger driving rains, greater windiness and more extended periods of drought followed by intense rainfall - especially in the uplands and in the sandy and peat soils of the Fylde plain. Milder winters in the uplands would allow farms to extend the period during which livestock are put onto the hills. This will increase the pressure upon the land and increase the risk of erosion. Climate driven changes in the vegetative system in the uplands might alter the prospects of upland farming, though the latter is likely to be far more sensitive to subsidy policy and markets. Nevertheless, the impacts of climate change upon the use of upland land needs to be included in the present debate on the future of upland farming. Aquaculture – especially trout farming - is likely to be adversely affected by an increase in temperatures due to deoxygenation of the water.

Technological and policy changes will alter the above risks. For example, more precise pesticide delivery systems will reduce the risk of pollution, whilst reduced sludge disposal at sea will increase the demand for land-based disposal, increasing the risk of pollution. There has been a trend towards larger, more intensive animal production units, with large quantities of waste being disposed over relatively small areas of land. If this trend continues, in parallel with the predicted changes in climate, the potential for pollution events will be greatly increased.

Soils are the main source of the greenhouse gas **nitrous oxide** (N_2O). The highest emissions are from agricultural land receiving nitrogen fertilisers. Intensively managed pasture is estimated to produce three times as much N_2O as ungrazed grassland. Emissions of N_2O are largest from poorly drained soils and in moist warm climates. Climate change could therefore lead to an increase in N_2O emissions from soils in the North West.

Farmers' Perceptions and Experiences of Climate Change

Working with the land and the seasons inevitably makes farmers' cautious about reports of climate change. Their initial reaction is to interpret vicissitudes in weather patterns as cyclical rather than as manifestations of longer-term change. Thus the extremely wet summer of 1998 in the North West was perceived amongst the interviewees as similar to that of 1986, 1946 and several in the 1950s. Nevertheless, the run of particularly mild winters was noted (though the winter of 1998/99 was predicted to be a harsh one!). Day to day exposure to the elements helps farmers take such change in their stride and to be sceptical of the over-reporting of the issue of global warming. Some saw global warming as an issue accepted uncritically by an urban or semi-rural public, largely cocooned from 'nature' in offices, homes, shopping malls and cars.

Presented with possible climate change scenarios, farmers emphasised their inherent adaptability, both through experience and technological advances, to cope with the worst excesses of the weather. The shift from hay to silage making and the mechanisation of many farm operations means that nowadays fairly narrow windows of relatively fine weather are needed in which to gather in crops and grass. There was a perception of distinct advantages associated with climate change, particularly milder and shorter winters and earlier springs which would benefit crop growth and animal husbandry, although the precise benefits are dependent upon a complex mix of factors, not least economic conditions. More productive grasslands, and longer outdoor stocking periods, would reduce the need to buy-in animal feed for the winter and hence reduce costs. All-year outdoor stocking of livestock was a future possibility in a warmer climate.

Perceived disadvantages associated with climate change centred on pest control and the effects on vegetation of extended stocking, but also the implications for existing plant and animal biodiversity. The possibility that rainfall might increase and become more intense was not welcomed as it would impede the use of machinery and increase the likelihood of the poaching of land by cattle and leaching of pollutants such as nitrogen and sheep dip. Stock health would also suffer because of the higher incidence of infections. Farmers' speculated that the warmer winters of the 1990s had contributed to the greater incidence of pests which had affected upland vegetation, e.g. caterpillars in the Howgills during the summer of 1998. The issue of coastal flooding met with considerable concern and the option of 'managed retreat', possibly involving the abandonment of high quality farmland, was seen as 'sacrilegious'. Extensive consultation would be needed to develop consensus on a change in the present extent and standards of protection from coastal flooding. The issue of compensation for productive land lost is likely to be particularly important. Diversification of farm enterprises, both into non-agricultural options such as golf and agricultural options such as pick-your-own, were noted as particularly vulnerable to the vicissitudes of the weather, as the summer of 1998 proved. Hotter, drier summers, however, might well prove beneficial to such diversification, depending on commercial and planning considerations.

Horticulture could prove rather more resilient to the effects of climate change because of the use of glasshouses. On the plus side, the higher temperatures would reduce heating bills. Increased cloudiness could affect light levels and hence reduce crop growth (though the current scenarios suggest only a very slight change in cloud cover). Horticulture is a significant aspect of the local economy in Lancashire and a higher incidence of extreme events such as flooding and storminess could be of significance both for 'glass' and 'non-glass' growers.

In conclusion, changes at the farm level have been, and will continue to be, largely the result of externally driven influences such as economics rather than a response to changing climatic conditions. For short term planning, farmers had little faith in weather forecasting, having experienced this as frequently wrong and 'southern biased'. Day to day management based on local knowledge and experience has generally sufficed, despite an acknowledged increase in the unpredictability of the weather. Thus incremental adjustment, rather than discontinuous adaptation, to climate change is the more likely response. The more immediate concerns of farmers in the North West are currently focused on policy making, economics and power relations and their impacts on farming and farm restructuring.

Forestry

At around 6%, the North West is the most poorly wooded region in the UK. The predicted changes in climate combined with the increased levels of CO_2 in the atmosphere, and current enhanced atmospheric inputs of nitrogen, are likely to result in increased tree growth rates. Analysis of regional data on forest production in Europe has shown significant increases in forest growth and production over the last 40 years. These increases will be due in part to improved silvicultural practices but some of the increase will be due to the enhanced CO_2 concentrations and greater nitrogen deposition. The milder winters may also allow a wider range of species to be considered. Species such as beech and small-leaved lime are likely to extend their northerly range, whilst species such as alder, cherry and willow could suffer from higher soil moisture deficits in the growing season. Extreme events such as late spring frosts and storms might be particularly influential in certain locales. In the uplands the altitudinal limit to production forestry could increase but exposure and the effects of strong winds in dislodging trees (windthrow) are likely to remain the main controls here. On the negative side, milder winters could result in an increased incidence of pest outbreaks. The increased production and greater species options would, in principle make forestry a more attractive land use option but the main control on planting decisions will remain timber prices and incentives.

There has been considerable discussion about the potential of forestry as a carbon sink and of the possibility of balancing, or trading carbon emissions against new forest plantings. New plantations established on former agricultural land certainly result in a net sequestration of carbon both in the trees themselves and as a result of an increase in soil organic matter. There is certainly potential for further planting the lowland, agricultural areas and the lower slopes of the uplands of the North West but any expansion will be dependant more on economic policies than environmental factors.

The net effect on carbon stocks of planting on semi-natural, non-forest peats or peaty soils in the uplands, which are drained before planting, is less certain. The drainage and ploughing leads to an increase in decomposition of the organic layers, with resultant emissions of CO_2. The trees will accumulate more carbon than the pre-existing non-forest vegetation and forest litter will accumulate on the soil surface. The net effect of the loss of organic matter due to increased decomposition versus the accumulation of carbon in the trees and forest litter needs clarification. It had been widely assumed that the result would be a net loss of carbon. But a recent study in southern Scotland suggests that, in the first 30 years after planting there is a net accumulation of carbon in the forest-soil system compared with the grass/heather-soil system it replaced. A second study is now in progress to see if the result can be confirmed and to determine the impact over a full forest rotation. There are suitable areas for afforestation in the uplands, given appropriate ground treatment, if the current work confirms a net accumulation of carbon in the forest system. However, there would almost certainly be considerable public opposition to any significant expansion of forestry in the uplands. The longer term significance of carbon sequestration as a result of afforestation depends on the use of the wood once the trees are felled, for example whether or not they are used for constructional timber, for newsprint or as an energy source, and whether or not the site is replanted following felling.

KEY MESSAGES

- Agriculture in the North West is likely to be affected by climate change, probably through enhanced and new crop growth but certainly by water supply problems especially for horticultural enterprises.
- Earlier springs and milder winters should be of benefit to animal husbandry in both uplands and lowlands, though problems of soil erosion, pollution and animal heat stress could follow,
- Forestry is likely to benefit through enhanced tree growth, although there will be problems of exposure at higher altitudes and stress on some species because of drought, pests and diseases.

….. AND QUESTIONS

- Will climate change increase or decrease the productivity of the grasslands?
- Will climate change increase or decrease soil erosion on agricultural lands?
- What is the increased risk of farm waste run-off?
- How much will farmers benefit from savings due to potentially more productive grasslands?
- What new species and varieties of crops and trees could be introduced into the North West, and what might be lost?
- What new measures are required to maintain the irrigation of horticultural land?
- What factors will influence farmers' and forest managers' readiness to respond to climate change?
- Does afforestation in the uplands increase or decrease the carbon storage of the soil-habitat system?

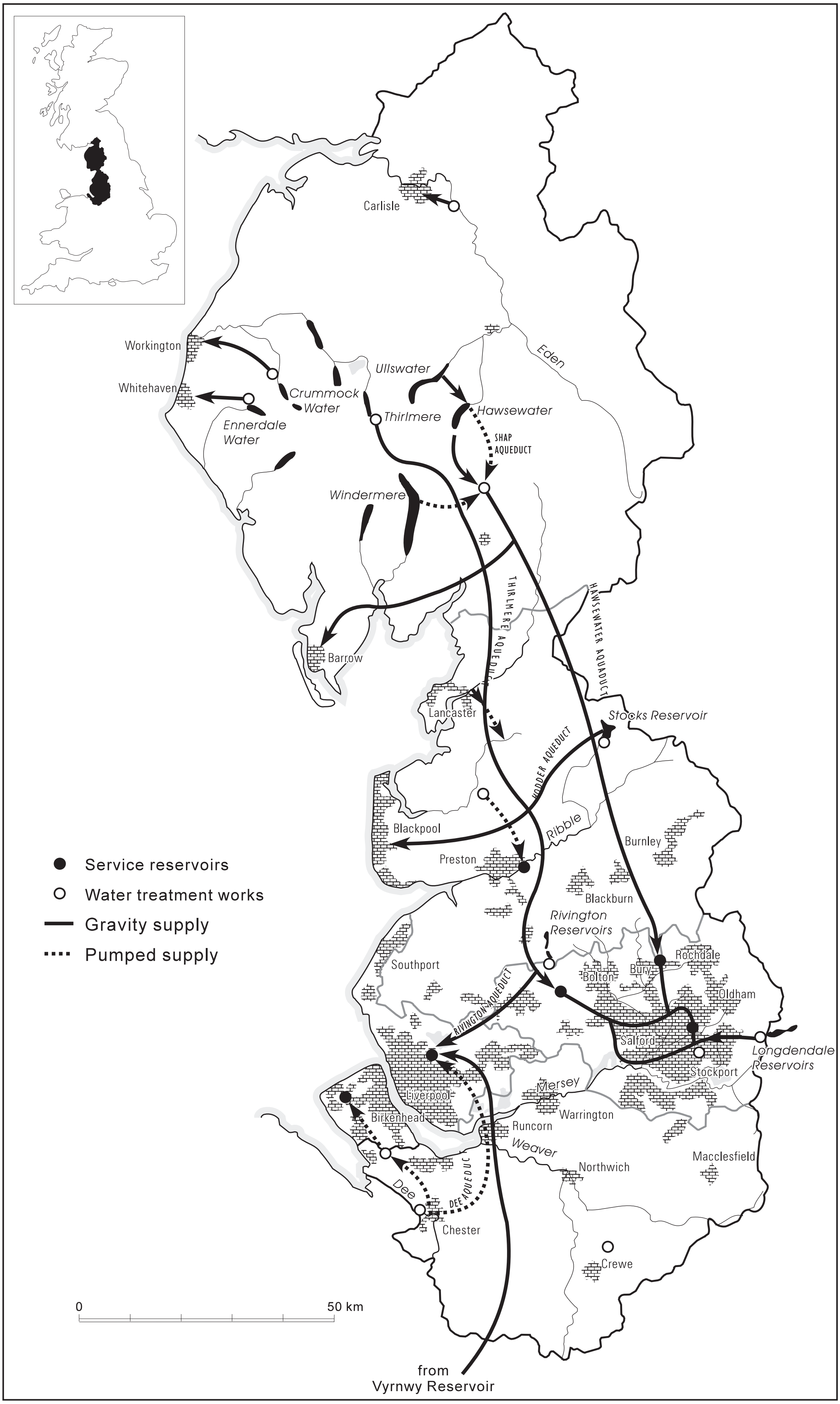
Water Resources and Water Balance

Water resource management has had to cope with large variations in rainfall patterns over the past few decades, and this provides much valuable experience for dealing with variation in supply due to climate change. The predictions of the effects of climate change on rainfall in the North West region are of low confidence, and relate only to the average year conditions. Because water supply availability is most sensitive to the intensity and duration of droughts, the average year predictions cannot be used as the basis for long-term planning. If summers become generally drier and winters generally wetter, it will become necessary to collect more water during the winter period, involving increased pumping from rivers, in order to have the reservoirs full by the start of the summer period. This could also necessitate the provision of additional reservoir storage capacity. The dry summer of 1995 was preceded by one of the wettest winters on record, and this might represent the general pattern of weather by the middle of the 21st century. In autumn 1995, reservoirs in the Rochdale/Oldham area were from 0-20% full, having been 100% full in the spring.

One of the strengths of the Region's water supply system is that it is highly integrated. Major aqueducts from the Lake District to Manchester and from North Wales to Merseyside, and associated transfer links, enable water to be transferred around the region. The diversity of sources from reservoirs and lakes in the Pennines, the Lake District, and North Wales, to the rivers Dee and Lune, and groundwater in Cheshire, Merseyside and the Fylde, also provides additional security. During winter and spring 1995-6, when some Pennine reservoirs were effectively emptied, supplies were maintained by transfers from the Lake District, and from the River Dee. Should climate change result in increased severity and frequency of droughts there will be significant challenges for water supply. Further water conservation, leakage reduction, and efficiency measures, as well as some new water source development, will be necessary to ensure the continuing reliability of water supplies.

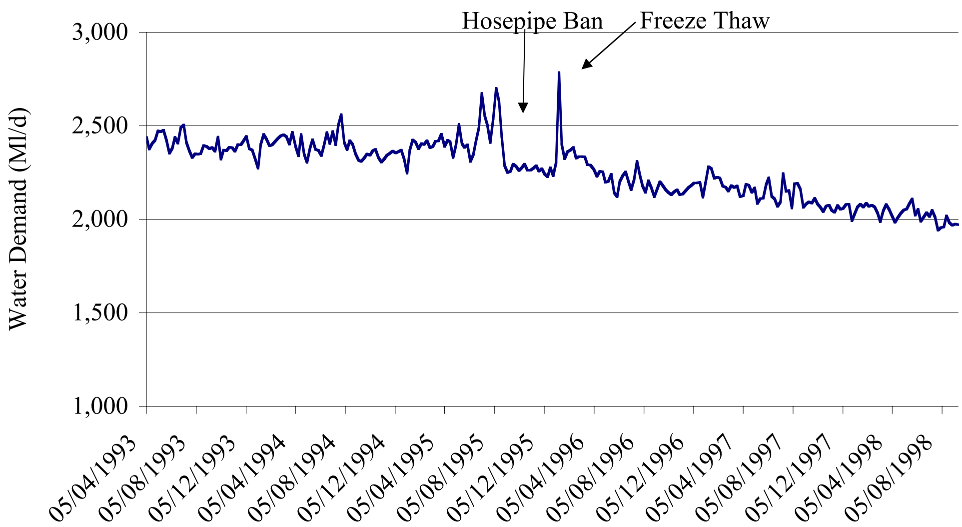
Some of the water supply in the North West already suffers from colouration due to the presence of dissolved organic carbon derived from peaty soils. The problem is likely to become worse as temperatures, and hence decomposition rates, increase and periods of drought become more common. Most serious for water colouration would be periods of drought followed by intense rainfall events. The removal of colour from water increases treatment costs.

The long dry period of 1995/6 led to problems for waste water management when the rains eventually came in 1996. Pollutants had become very concentrated because of the low water volumes. Intense rainfall acted to flush out such chemicals, raising problems for water quality and ecological impacts. Intense periods of rainfall can also flood the sewage systems and lead to sewage outflow into water courses (foul flooding). There are a number of combined sewer overflows in the North West dating back from the Victorian times, which are already insufficient to cope with current volumes of waste water, and these will be even more stressed by higher winter rainfall. Modern facilities for waste water treatment are conventionally designed to cope with three times the projected load, i.e. a safety margin is already included. If changed rainfall patterns were to increase the load on such facilities (say during the winter), would a greater safety margin be required? The capital expenditure involved in increasing the safety margin is very large. Nevertheless, waste water treatment managers will need to consider including climate change 'headroom' into the design of future waste water treatment infrastructure.



Source: NWW Ltd.

North West Water Demand, 1993 - 98



Source: NWW Ltd.

KEY MESSAGES

- Rainfall patterns show a high degree of natural variability.
- Predictions of regional changes in rainfall due to climate change are highly uncertain.
- A highly integrated system in the North West provides protection from rainfall changes, but an increased frequency and severity of drought would require expensive adaptive responses, e.g. pumping more water from rivers in winter into reservoirs and possibly new supply options.

….. AND QUESTIONS

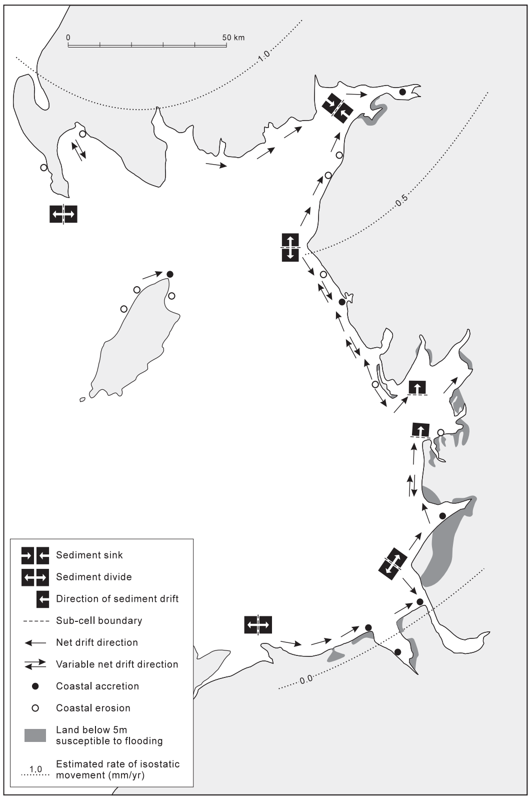
- Can regional-level scenarios of the impacts of climate change upon rainfall patterns be improved?
- Are new supply options required in the region because of climate change?
- What are the ecological impacts of low and/or more variable and extreme water flows in rivers, streams and lakes?
- Does climate change mean that waste water facilities have to be designed with an additional safety margin in the future?

Coastal Zone Management

Large stretches of the North West coastline are potentially vulnerable to sea flooding because they are only just above the high tide sea-level. Particular areas at risk are the Fylde coastline (Lytham to Fleetwood and Knott End, including Blackpool), Morecambe and surrounding parts of Morecambe Bay, Southport to Sefton coastline, the Solway Firth and the Wirral. The major threat on the timescale of the next century is not changes in the mean sea-level, but rather the effect of climate change upon tidal surges, winds and storms. It is the combination of high tides and strong westerly and south westerly winds - increasing wave height and tidal surges - which are the main threat to the Irish Sea coastline. Major sea-level change and marine flood events have occurred during the past 10,000 years and during that time the coastline has looked very different from today. During the recovery from the last ice age, the sea levels in the region rose at the astonishingly rapid rate of 36cm per decade.

The floods of 1977, 1983 and 1990 are well remembered in the region's coastal towns and villages, and in response extensive flood and erosion protection schemes have been designed and put into place in towns such as Blackpool and Morecambe. Such structures are very expensive infrastructural investments, mounting to many millions of pounds over 10 or 15 year periods. Yet, their design life is likely to be foreshortened because of climate change.

Sediment Transport & Coastal Cells in the North West (source: Sustainability North West, 1997)



PERSONAL COMMENTS ON THE FLOODS OF 1983 IN MORECAMBE

"We did not really think the water would come in - I suppose we should have - but we didn't. We were concentrating on protecting the front of the building and then suddenly from the back came this gurgling sound. I first of saw the water coming in from round the back, and then it came in through the front like a river. We have nothing left at all. It was far worse than in 1977 when we had about nine inches in the basement. Now it is six or seven feet".

"You've got to see this sort of thing to believe it. You think the whole sea is going to come pouring in. The water smashed in through both the front and the back of the basement... I have lived here for 11 years and this is the third time this has happened" (local resident)

"The sea has never frightened me before. But it did last night - it was so rough. The house was shaking and it was almost as if the whole place was going to go. … The hotel is replaceable - it's the photographs and everything from way back that you cannot replace, our wedding photographs and pictures of the children as babies. I never dreamed it would be so bad" (local hotel owner).

An increase in sea-level rise of 4mm/year has been included in coastal defence structures in the North West, following guidelines from the Ministry of Agriculture, Fisheries and Foods (MAFF). The change in tidal surge height and in wave height as a consequence of increased south westerly winds has not yet been considered however. Increased wind speeds are predicted from climate models, and it seems a reasonable first approximation that prevailing winds will continue to be south westerly. Theoretical considerations suggest that an increase in the chance of tidal surges arises from an increase in mean sea-level. For both of these reasons, it is reasonable to suggest that current sea-defences will be increasingly challenged over the next 50 to 80 years, especially when local circumstances such as beach and dune erosion are also taken into account. The value of insured property which is defended by such sea-defences, and is defined as being as high risk, is much greater that the cost of sea-defence structures, however (£192 million for the North West coastline for just one insurance company operating in the region).

Whilst managed retreat is in principle an attractive coastal management strategy, in practice the opportunities are limited in many parts of the North West due to relatively high settlement densities. However, in those regions where managed retreat could be planned, this is a policy option worthy of further appraisal and is currently being investigated by the two Coastal Groups in the region preparing detailed Shoreline Management Plans. Storm events in coastal resorts can be quite significant events in their history, even turning points. This is because storms damage coastal features such as piers, promenades and gardens which, if not properly maintained, serve as a very visible indicator of decline and are liable to be further damaged or even destroyed in future storms (as happened to the West End Pier in Morecambe in 1927 and 1977). Furthermore, the perception that property and contents insurance cover is difficult to obtain in a coastal resort may deter inward investment (as again may have happened in Morecambe, though substantial recent investment in coastal defence there appears to be turning the situation around). Stormy weather also affects coastal activities such as shipping and fishing (discussed under economic impacts).

KEY MESSAGES

- Existing sea-wall defences take account of sea-level rise but not necessarily changes in tidal surges, and wave heights which pose the greatest threat.
- The ability of current defences to protect against extreme tidal events will be increasingly challenged from the 2020s onwards.
- Modular sea-defence structures allow adaptation to changes in extreme events.

….. AND QUESTIONS

- Can studies of specific coastal localities be conducted which explore scenarios of likely changes in extreme events due to climate change, combined with local knowledge of the response of the specific coastline?
- How should opportunities for managed retreat be evaluated?

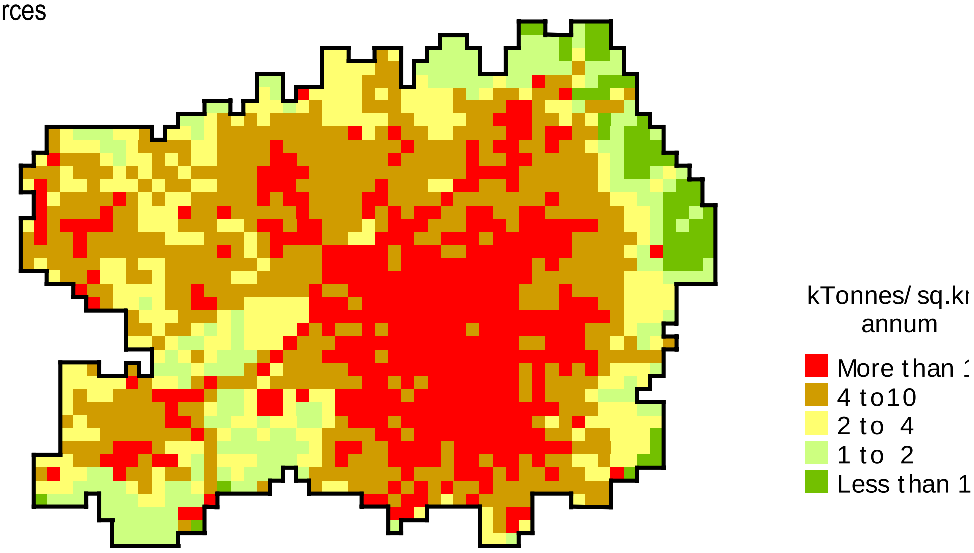
Urban Core and Urban Fringe

Urban heat islands will become increasingly common, resulting in discomfort to residents and occupants of buildings. Street trees are likely to be severely adversely affected by water deficit and species more suitable to the likely climate of the 2050s should be being planted where the opportunity arises. The current re-design of many parks and gardens in the urban core and fringe with lottery funds represents an important opportunity for taking account of climate change, e.g. in the selection of species and in the design of open spaces. Water tables are rising in parts of the urban core due to displacement of manufacturing industry, e.g. in Liverpool and Trafford Park. The problem of rising water tables is likely to worsen due to higher winter rainfall. Increased winter rainfall will also increase the possible exposure to toxic substances found on contaminated land and the risk of old mine works flooding, potentially contaminating water systems. The Government anticipates that 141,000 additional households are required in Greater Manchester alone by 2011. Throughout the North West there will be an increasing demand for water and electricity from new homes and offices, and from garden-use, so increasing the potential future sensitivity to climate change.

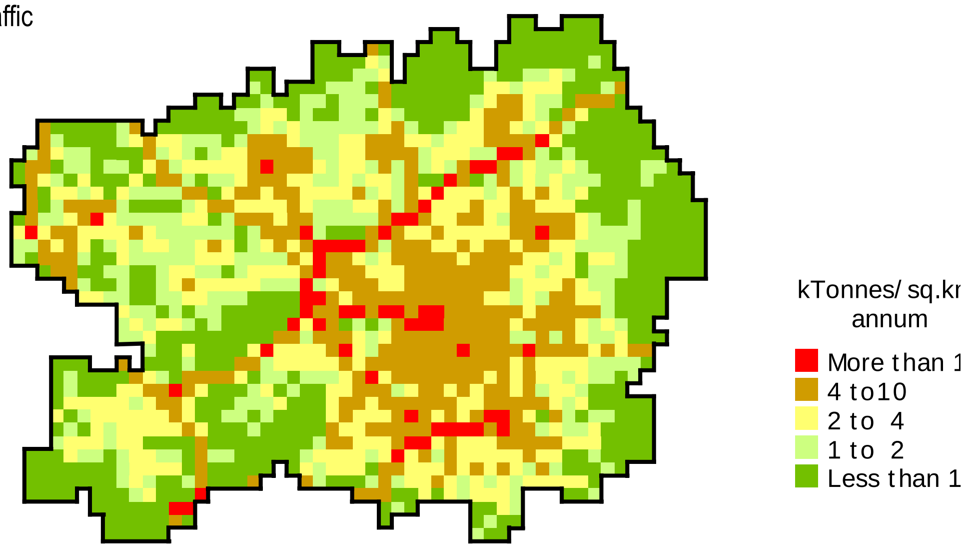
CO_2 Emissions in Greater Manchester

(source: London Research Centre, 1997)

a) From all sources

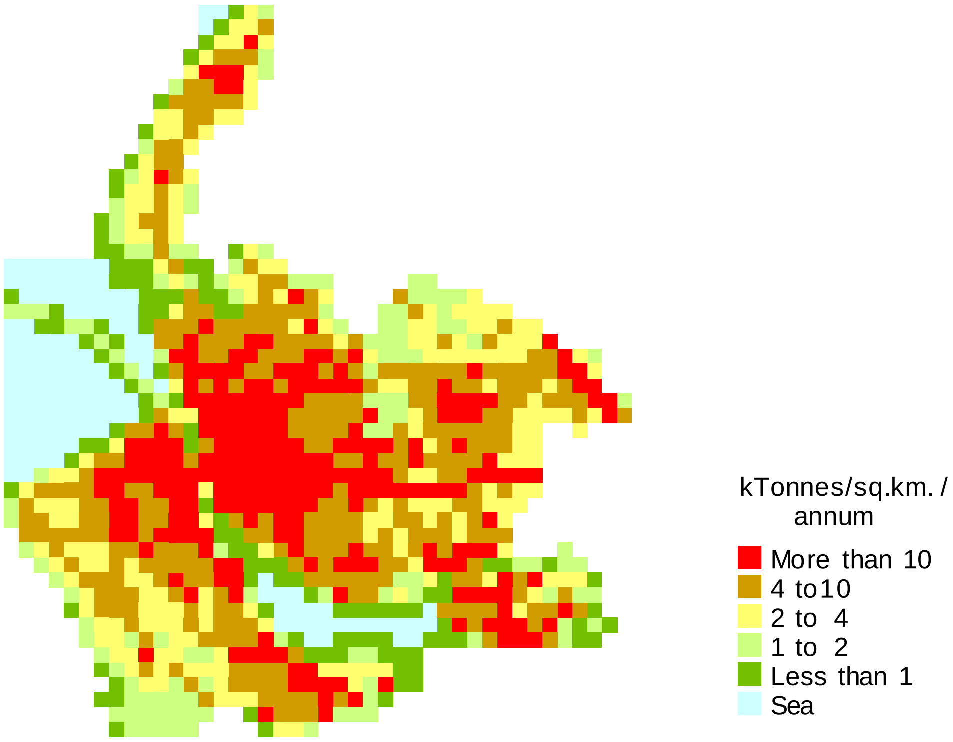


b) From road traffic

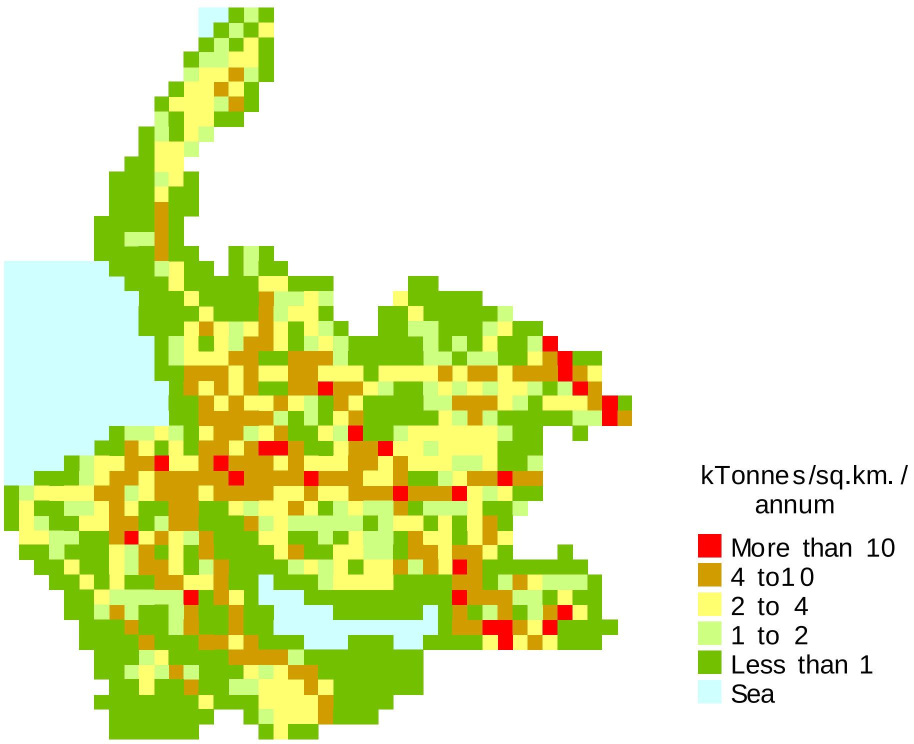


CO_2 Emissions in Merseyside
(source: London Research Centre, 1997)

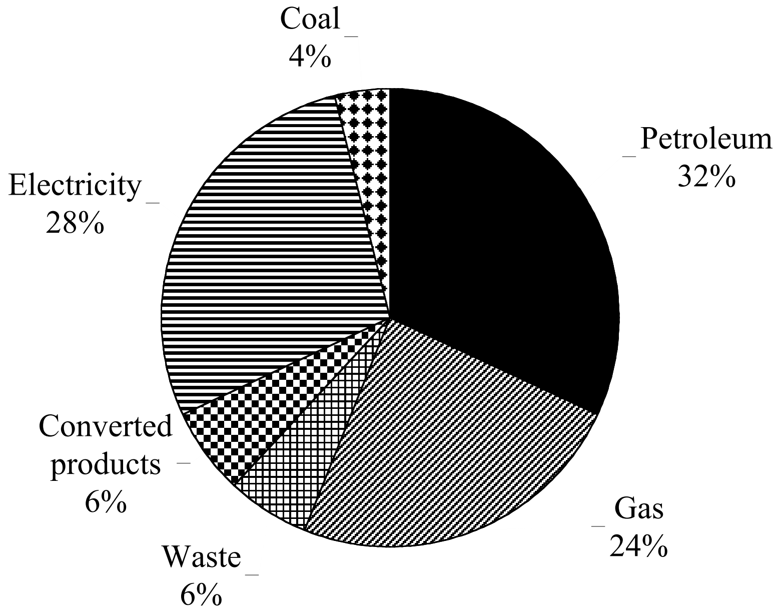
a) From all sources



b) From road traffic



Source of CO_2 Emissions in Greater Manchester (source: McEvoy et al, 1998a)



KEY MESSAGES

- Street trees will be increasingly needed to provide shelter from the sun, but current species are less suitable to future climate conditions.
- Re-design of parks and gardens needs to take climate change into account. Greater care of young plants is likely to be needed.
- Rising water-tables could increase flood risks and threaten to increase exposure to toxic chemicals.
- Higher demand for water from new housing and from garden-use will increase the sensitivity to future climate change.

The Cultural Heritage

The cultural heritage of the region is manifested in its land and buildings: ancient burial sites, historic buildings, gardens, parks and the very appearance of the landscape itself. Often, by virtue of their age, many of these artefacts are highly vulnerable to changes in their environment, with alterations in such variables as rainfall, sunshine or humidity having a disproportionate effect. These monuments represent tangible links with the past and are often looked to accompany us into the future as expressions of our personal and community identity. The National Trust has particular concerns in this regard with interests which cover a broad sweep of environmental concerns: the coast, nature conservation, historic gardens, archaeology, soils, tourism, agriculture, water resources, historic buildings, forestry and energy use. As an organisation, it is perhaps uniquely placed to influence land management practices in some of the most sensitive upland environments (owning around a quarter of the Lake District for example). Equally, climate change brings about challenges for estate management which have to be addressed holistically. The extreme events of 1995 saw notable problems throughout the North West for the Trust with evidence of soil erosion after vegetation die-back in the Lake District following water deficit and heavy grazing and local shortages and drying-up of on-site bore hole water supplies. The Trust considered introducing demand management measures (particularly with regard to leisure and tourism) to attempt to mitigate and anticipate the effects of visitor pressures. There is clear evidence of more visitors to National Trust properties in good summer weather but some weather-effects upon visitor patterns are more subtle. For example, some of the highest visitor numbers to Lyme Park (on the western edge of the Peak District) occur during snowy weather because of the suitability of the Park for tabogonning. A decrease in snow is likely in the future and hence these local visitor number peaks (and income streams) will be reduced or disappear.

For some cultural artefacts, such as buildings, the effects of climate changes can be anticipated and planned for. The temperature and light control of rooms containing sensitive fabrics, paintings and furniture can be better controlled to protect artefacts from increasing temperatures and more sunlight hours. This will, however, cost more money in air conditioning and could require more efficient cooling systems to be installed. Repair of roofs will have to take increased wind speeds due to climate change into account, which again is likely to incur additional expense. The dilemmas raised for natural resource and land management by climate change centre on how far there should be adaptation to changed conditions, ranging from seasonal planting regimes and greater attention to plants to ensure they do not die from water stress, to the management of tracts of semi-natural countryside for wildlife. Climate change is a powerful external factor which may force the issue of how far it is desirable or indeed feasible to maintain the *status quo* for the conservation of habitats and species and hence the utility of 'traditional' land management practices. Allowing for dynamism in the natural environment, allied with careful environmental stewardship through pollution prevention, soil conservation and adaptive management, for example, is likely to form the basis of a more dynamic approach in the future. In essence, this entails conserving natural processes as opposed to natural 'products' or 'end points' *per se*. Climate change may provide the stimulus for some radical thinking about the management of complex semi-natural systems, an opportunity that is being embraced by the National Trust.

KEY MESSAGES
- Fabrics, paintings and furniture are sensitive to climate change and adjustments in their care will be required, incurring additional expense.
- Climate change will influence the use of the cultural heritage, potentially increasing visitor numbers.
- Old buildings are particularly vulnerable to storms and other extreme weather.

….. AND QUESTIONS
- How is human-induced climate change incorporated into a dynamic approach to environmental management?

Other Future Changes

Other changes in the future will increase or decrease the sensitivity of the exposure unit to future climate change. We can aggregate all the pressures upon ecosystems and think of a high level of ecosystem pressure and a low level of ecosystem pressure. The following pressures will, for instance, increase the stress upon ecosystem processes and components: land development, road building, lax conservation policy, agricultural policy which encourages higher levels of grazing, short-term water resource policy, a static approach to ecosystem management, and so on. If such pressures are exerted upon ecosystem processes and components, the latter will be less able to cope with yet further pressures arising from climate change. Meanwhile, if such pressures are lessened, then ecosystems will in principle be more able to cope with climate change. It follows that one policy response to climate change, is to undertake non-climate related policies which render exposure units more resilient and robust to future changes such as climate change. So, for example, reducing pressure upon the uplands from grazing will make upland ecosystems more resilient and better able to cope with climate changes. The ability to enact and/or change policy is an important consideration in assessing the mix of measures required to respond to climate change. Are there policies which can be undertaken that will increase resilience/ robustness at no significantly greater cost?

KEY MESSAGES
- Climate is only one amongst a range of variables which are undergoing change into the future.
- It is possible to consider change through concepts such as aggregate 'ecosystem pressures'.

Regional Economic and Commercial Interests

Introduction

The typical likely response to climate change amongst those North West businesses we interviewed was experience-based incrementalist reaction. Most businesses prefer to wait and see what actually happens to the weather before investing resources in responding. Chemical companies will, for example, adapt plant equipment to cope with higher temperatures if a run of hot summers is encountered (four 1995 summers in a row for one company). They, like most businesses, will need fairly strong 'on the ground' evidence that the weather - at their specific plant - is changing before they take action which incurs a financial outlay. Such an approach makes much commercial sense, as it avoids the outlay of resources until absolutely necessary, and at a scale which corresponds with the problem. If the problem gets worse, the organisation can take more action, until the issue is adequately managed.

On the other hand, it does require organisations to be 'light on their feet', that is to monitor the situation and to have institutional mechanisms which allow a rapid response and adaptation, for example if more extreme events than expected take place. Not all organisations or economic sectors are 'light on their feet' with respect to climate change because of the novelty of the issue and because it is a long-term problem which is beyond the time-frame with which most businesses are operating (1 year ahead to 5 or 10 years ahead for most sectors). In the North West, only the water and energy utilities, and several large multinational companies, appear to use planning horizons of more than a decade. As an example, architects and building designers are still using climatic data from the 1960s and 1970s in assessing heating and cooling requirements to ensure given occupant comfort levels, even though they are typically using a design life of 50 year. Existing buildings may well have to be refurbished in the future because of changed climatic conditions. We note, however, that a major revision of the voluntary guidance on climatic data for building design is underway which uses much more recent climate data. Factoring-in climate change can provide the impetus for better design more generally, with attendant savings on energy and water costs, and higher comfort levels. The Environment Agency's new building in Penrith, for example, uses 80% less CO_2 from electricity than its previous (smaller) building, and 55% less CO_2 from burning gas. Water consumption has also fallen from 8m^2 to just 3.5m^2 per employee per year.

Non-climate related investment decisions will sometimes change the sensitivity of a facility to climate change, and in these cases there may be 'double-dividends' from including climate change considerations into the decision-making process. Generally, companies should be aiming to increase their 'climate headroom', i.e. factoring-in the likelihood that the climate will continue to change in the

design of plant, processes and in making investment decisions. Just as for managers of natural resources, climate change is a useful 'hook' for companies with which to think about their future environment. This is because climate change is one of the very few future trends which we are a bit more certain about than most.

KEY MESSAGES

- Businesses respond to climate change through experience-based incrementalist reaction and adjustment.
- Fairly strong 'on the ground' evidence of change in weather conditions will be required before companies respond to climate change, especially if it involves resource investment.
- Climate change could function as a useful 'hook' by which to think about the future development of society and the economy.

The Chemical Industry

There are important issues for the chemical industry arising from the common need for cooling systems in chemical processes. A significant increase in extreme temperatures (over 25-30^{o}C) would limit the effectiveness of some currently installed cooling systems, and would increase their running costs or necessitate installation of new cooling infrastructure (additional costs of hundreds of pounds to hundreds of thousands of pounds depending on the plant size). Rising sea-levels, more extreme tidal surges, rising water tables and more frequent river flooding pose environmental management issues for chemical plant located at vulnerable sites, of which there is a significant amount in the North West region. Around the Mersey Estuary, for example, there is £35 billion of plant investment. Some 400 of the 2,000 sites in the UK which are registered under the Integrated Pollution Control (IPC) legislation are located in the North West (over half of which are chemical plant) and 300 of which occur along the Mersey Estuary. However, there are also important clusters of chemical-related firms in Greater Manchester, along the Ribble and Lune Estuaries, and along the west Cumbrian coastline.

Water quality is also an important issue for companies taking water out of rivers; it is adversely affected by intense rainfall events, flash flooding and low-flows in summer dry periods. Increased turbulence in rivers reduces water quality, adversely affecting some chemical processes. Closed water systems or more water treatment are adjustment options, but can be costly. Low summer flows would also limit the permissible emission discharges because of the more concentrated water.

Increased rainfall will challenge many existing wastewater treatment systems, especially at chemical plants where all on-site water is treated. Such systems are typically designed for a 1:3 to 1:5 year extreme rainfall event, but such events could become the norm in the future. The more frequent flow of waste water into water courses could result with serious ecological impacts. Adjustment options include construction of waste water treatment systems, or separation of rain water from plant waste water, though the capital expense would be large.

The UK Chemical Industry is an important contributor to greenhouse gas emissions in the Region, with significant point sources including large oil refineries, gas scrubbing, cement manufacture and by-products associated with the manufacture of HCFC refrigerants (Arcton 22). For example a single plant at Runcorn is estimated to contribute 2% of the UK's total greenhouse gas emissions. However, the chemical industry has entered into a path-breaking voluntary agreement with Government by which they will aim to reduce their emissions of CO_2 by 20% by the year 2010.

Other Industrial Sectors

Other industrial sectors are influenced by climate change through the disruption to work arising from high ambient air temperatures during hot summers. The problem is especially important at sites where protective clothing is worn and/or work has to be conducted in restricted spaces and/or where older factory buildings are in use. Given that high working temperatures have already been a problem at many factories during the hot summers of the 1990s, it is very likely that this problem will become significantly worse, resulting in disruption to production and work activities, and generally lowering worker motivation (and hence productivity). One food processing company has already installed an air conditioning system in its factory at significant capital expense, and significant running costs, especially during hot weather. New cooling and air conditioning systems may be required, or else alternative working arrangements may be required to avoid worker exposure to the hottest parts of the day. There are knock-on effects for the insurance industry because work stress, and liability for causing work stress, is a growing area of business and claims.

KEY MESSAGES

- Some chemical processes will require more cooling.
- Water quality might suffer from increased storm and flooding events.
- Much of the chemical sector and other manufacturing in the North West is vulnerable to more extreme tidal events and flooding.
- Higher summer temperatures will have an impact upon work practices.

….. AND QUESTIONS

- What is the economic cost of high working temperatures for large firms and SMEs?
- Exactly what degree of change is required for them to adjust their working practices and/or planning strategies?

Transport

Some ports and harbours in the North West may be significantly affected by rising sea-levels, high tides and tidal surges. Where Ports and Harbours have lock gates which can exclude the sea (as at the Mersey Docks and Port of Workington) the problem is less serious. The sea might still breach the lock gates (as it did at Glasson Dock in 1990) and find its way into dry docks where the interior of ships could be adversely damaged, or upstream into canals and other waterways from which flooding of property and land can result. Twenty-four hour Ports, such as Heysham Harbour, are more sensitive to sea-level rise and high-tides associated with driving south westerly winds. Significant expenditure on adapting existing infrastructure might be necessary, though this may be achieved through natural replacement of that infrastructure in the next few decades (provided that climate change issues are considered). Also important to some Ports and Harbours is the changing siltation patterns of rivers, such as the Lune in the case of Heysham. Such siltation is influenced by weather patterns: for example, low river flows result in higher sedimentation, and can cost ports and harbours much money in enhanced dredging operations. Wind-driven siltation from the sea is important at Fleetwood, and increased westerly winds would increase dredging costs significantly.

Ships are currently designed to manoeuvre (e.g. in ports) in particular weather conditions. Higher average wind speeds would demand more powerful ship engines, especially given the expected lifetime of ships of 20–30 years. An increase in engine thrust requires a more than proportional increase in engine horsepower, so the additional capital costs would be significant. Ship cargo would need to be more protected from higher winds and more stormy weather, perhaps requiring a change in ship design. Commercial and recreational fishing activity is hindered by stronger winds. Stormy weather prevents the laying down of nets, which reduces catches and increases prices for fresh fish (as happened in the mid-late October storm of 1998). Several of the canals in the region are especially vulnerable to low summer rainfall, and in the summer of 1995 suffered from lack of water. This will reduce recreational and commercial use of canals and have adverse effects upon canal biodiversity unless alternative means of increasing water supply are identified.

Some railways in the North West are situated on the coastline and are vulnerable to flooding. Along the west Cumbrian coastline, for example, flooding of the railway line already occurs. Rail Track has recently invested significant resources to reduce flood risk of the line in that region. Other railway lines will become vulnerable to flooding, however, due to extreme tidal events. The underground railway line in Liverpool has been more susceptible to water intrusion recently, due to the rising water tables (caused by reduced water abstraction by industry). An expensive programme of tunnel re-lining and pumping has been carried out in response. Higher winter rainfall will cost rail operators more in pumping costs. High summer temperatures can cause buckling of railway lines, as well as causing fires along railway lines; tourist-based steam trains can be prohibited from operating if they pose a risk of lineside fires during hot weather e.g. as occurred in the summer of 1995 and subsequently. Trains have to travel more slowly when the temperature of the line exceeds 54°C, because of heat stress to the track. Asphalt road surfaces can melt when high temperatures are reached and road maintenance becomes more difficult. Air transport payloads have to be reduced at higher temperatures due to reduced air density; this would require reduced cargo and passenger loads, particularly at airports with shorter runways. This is already an issue at some airports, though Manchester Airport is relatively immune to the problem because of its long runways.

Interactions between transport and other sectors are illuminated by the summer of 1995, when the need for water tankers to feed standpipes in Yorkshire led to 2,500 tankers using two roads in Humberside every day for six weeks. The massive use of the highways led to damage and Yorkshire Water agreed to pay for the damage put at £1 million. Another example is the pursuit of more outdoor leisure activities in hotter, drier weather such as cycling, which may result in increased cycle-related accidents and deaths (cycling fatalities did slightly increase in the summer of 1995 above normal). On the positive side, there should be less disruption to transport caused by severe winter weather conditions. This will have benefits to the public in addition to businesses.

KEY MESSAGES

- Some ports and harbours are vulnerable to more extreme tidal events and sea-level rise.
- Major infrastructural adaptation may be necessary by the 2050s or earlier at such ports.
- Changing siltation patterns, due to river flows and / or prevailing winds, can add significant extra costs to port operations.
- A change in the design of ships may be necessary to cope with higher winds.
- Fishing is disrupted by stormy weather.
- Coastal railways are at risk from extreme tidal events and flood-induced erosion.
- Railways and highways disrupted by very hot summer weather.

Energy Supply & Distribution

The impacts of climate change on the existing supply and distribution of energy in the North West are relatively limited. A 2°C increase in the average minimum temperature for all months of the year (perhaps reached in the 2050s) would produce a 1.5 % reduction in the load. That estimate does not take account of the possible increase in energy due to more widespread air conditioning however. A 1.5% reduction represents a significant financial saving to electricity users. Extreme weather events are a major threat to energy distribution. In the winter of 1997 there were very high (80mph), and unusually dry, winds off the Lancashire Coast at Heysham. As a result salt was deposited on electricity generators at the Nuclear Electric plants and, when it next rained, the insulation failed, causing the two reactors to be shut down (on Christmas eve), which is extremely expensive. The high winds during storms, such as those of winter 1997, also caused serious problems for the Regional Electricity Companies, NORWEB and MANWEB. Many lines were brought down in winter 1997 and electricity was not restored to remote locations for some days. Decisions about capital investment in the distribution system are long-term (up to 70 years) so that future climate conditions are important. More resilient supply systems might be required if lines are under greater threat from high winds. Drying-out of the soil might also limit the cooling from underground electricity cables (a phenomenon which led to loss of supply recently in Auckland, New Zealand).

The regional electricity companies are instrumental in responding to climate change through programmes to reduce CO_2 emissions. NORWEB has exceeded its targets under the energy efficiency/conservation programme known as 'Standards of Performance'. NORWEB has focused its work on insulation and energy efficiency of social housing in partnership with local authorities and housing associations, as well as on provision of discounted energy efficiency light bulbs and fridges to the elderly. NORWEB has saved over 550 GWh of energy – thereby reducing emissions of CO_2 by 200,000 tonnes. MANWEB, meanwhile, has been pioneering demand-side management in some of the remoter regions it serves.

KEY MESSAGES

- A slight reduction in winter energy demand due to increased temperatures.
- Increased risk of network failure due to greater storminess.
- Regional electricity companies have a major role in energy efficiency and conservation programmes.

….. AND QUESTIONS

- What will be the likely increase in summer energy demand due to expansion of air conditioning systems?

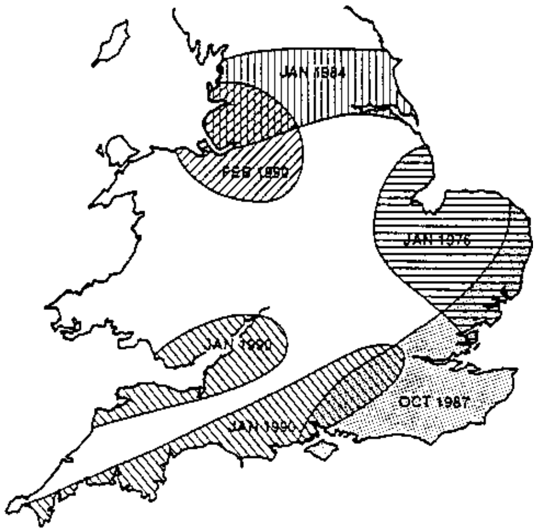
The Insurance Sector

Insurance companies in the region have underwritten insurance proposals for property which may be at greater risk as a consequence of climate change. The most serious risk in the North West is coastal flooding, followed by storm damage and river flooding. The major coastal protection works which have been undertaken in the last two decades in the region have certainly served to significantly reduce the risk. Nevertheless, if a tidal and storm event currently classified as a 1:100 year event should occur more frequently as a consequence of climate change, which we believe is a reasonable assumption, then the design specifications for the coastal protection works may be inadequate. One company estimates that its exposure to coastal flooding in the North West may be £192 million. No figure is available for the entire insurance industry's vulnerability to flooding on the North West coastline, but it is likely to be an order of magnitude greater than the above figure. The sector is likely to adopt more risk-based underwriting approaches as more information emerges about flood risk at specific locations. This could mean restricting cover in some regions or requiring special precautionary measures in some property. The room for manoeuvre of the insurance companies is likely to be limited by the intense competition in the sector, by the limited information and resources for analysis, by the scientific uncertainties, and by commitment to the equity principle which argues for less differentiation of the market risks. On the positive side, claims for flooding from burst pipes should go down as winters become warmer. New insurance markets may also open-up as new businesses and industries emerge in response to climate change (e.g. off-shore wind energy, new food processing, new agricultural activity, tourism and recreation, etc.)

KEY MESSAGES

- Substantial insurance industry's exposure in 'high risk' coastal flooding area. (£192m for one company alone; the entire sector's exposure is likely to be an order of magnitude greater).
- Changes in conditions and prices of insurance are likely to emerge over time as higher risk areas become better defined.

Areas of Maximum Windspeed for Five Recent Widespread Gales (source: Buller, 1993)

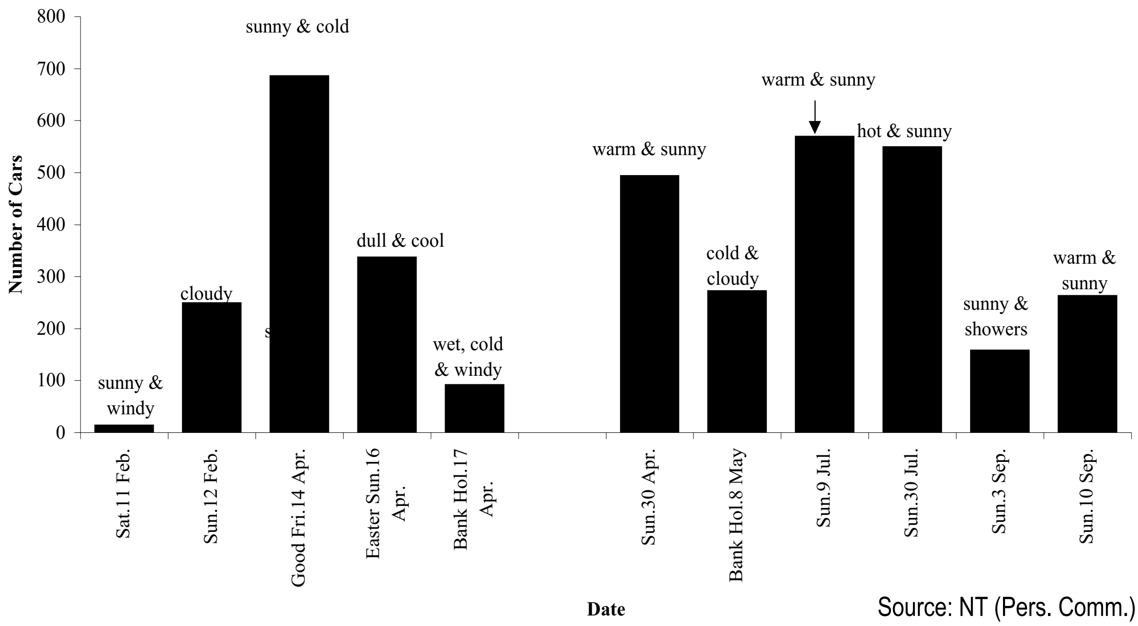


Leisure and Tourism

Leisure and tourism are major sectors in the North West of England. Some 18 million people visit the Lake District each year, a quarter of them from the North West. Around 35 million people visit Lancashire each year, with Blackpool alone receiving over 17 million! The direct and indirect income generated by tourism in Lancashire and Cumbria is in the region of £1.5 billion. Hotter, drier summer weather could have a major impact on tourism and recreation in the North West, especially if alternative destinations abroad become less popular as a result of climate change. (The North West might compete with other regions of the UK, Ireland and Northern France for a share of the displaced trade). The short-breaks market is increasingly important, and there is evidence that good weather is an important factor in decision-making to take a short break.

Wetter summers would not be beneficial, though the current level of tourism in the region is supported in what has been a relatively cold, windy and wet climate. Tourism may become more summer-season based, reflecting better summers, and wetter and stormier winters, especially if hot weather became more reliable and rainfall concentrated in intense events. Would the out-of-season tourism market become less viable? Not necessarily, depending on other social and economic trends and development of all-weather tourist attractions. One study identified a decrease in expenditure on tourism six months after a warm spell, suggesting that fewer winter breaks may be taken when summer temperatures are high, though this behaviour could change if better summer temperatures became the norm. Another important non-climate variable is the 'greying' of the population which will increase the demand for recreational opportunities in the future. Increased tourism and leisure activities in the North West will have knock-on effects on transport, accommodation, entertainments, theme parks, activity-based sports facilities and resources, golf courses, coastal defence and other infrastructure, which need to be further explored.

Visitors to Lyme Park, Cheshire, on selected days in 1995



Source: NT (Pers. Comm.)

KEY MESSAGES

- Tourism and leisure are one of the potential beneficiaries of climate change in the North West, though much depends on the future reliability of hot and dry weather.
- The 'short breaks' market is likely to benefit most from climate changes in the short-term.
- The long-term viability of coastal resorts depends upon the adequacy of sea-defences and on the continued maintenance of coastal infrastructure such as sea walls and peers.

….. AND QUESTIONS

- What will be the knock-on effects of an increase in tourism?

The State of the Future Regional Economy

In exploring the economic consequences of climate change in the future, we have to remember that climate change impacts will occur in a future world. If the regional economy is more vibrant in that future world, for example, the impacts of climate change will be much less than if the regional economy is in a poor state. A more healthy regional economy may be little comfort to the stakeholders who are still directly and adversely affected by climate change, but it does indicate that at the regional level there is more likely to be the capacity to respond to the negative effects of climate change. There will, for example, be new employment opportunities for people whose livelihoods are adversely affected by climate change. Meanwhile, the relative role of the North West region in the UK economy as a whole will also influence the significance of the impacts of climate change and the capacity to respond to those impacts. If a stronger regionalisation of policy emerges, and the North West region thrives, then again the impacts of climate change will be smaller in socio-economic terms, than if the region is less successful (though both positive and negative effects are likely to be marginal at the aggregate regional economic level). Note, however, that such economic analyses do not include impacts upon plants, animals, habitats, ecosystems, landscapes and cultural heritage, whose loss or alteration may be irreversible and perceived negatively by an environmentally-conscious public and regional policy community.

KEY MESSAGES

- The impacts of climate change depend upon the future state of the regional and national economy.
- The importance of climate change impacts will depend upon the concerns and perceptions of the public, as well as those of the stakeholders.

Public Perceptions of Climate Change

Any successful policy to address global environmental change requires the involvement of people living in the North West, both as 'citizens' and as 'individuals'. However, there are two main challenges:

(1) insufficient knowledge about how various publics in the North West perceive 'climate change' issues and what kinds of obstacle and opportunities people identify in addressing them;

(2) the general perception of the public regarding opportunities for meaningful and effective public action and participation within existing policy-making processes.

As a response to these challenges, there have been a series of recent policy initiatives from public, voluntary and partnership/stakeholders sectors. These initiatives include public consultation through Local Agenda 21 processes, community-based management of local environmental schemes (e.g. Groundwork Trusts), and *Citizens' Juries* for specific local environmental issues (such as waste disposal). Recent social analysis methodologies such as *focus groups* allow us to improve the state of the art of information gathering about public perceptions and to understand further the trends identified by the results of quantitative opinion surveys.

Bridging the gap between research and policy: *Citizens' Panels*

Citizens' Panels aim to bridge the gap between information gathering and more meaningful and effective public participation. Citizens Panels were designed and developed in the context of a European research project on climate change and sustainable development called ULYSSES and aim to combine:

(a) intelligent and culturally sensitive information gathering (that might be relevant and useful for policy-making institutions); with

(b) direct contact and involvement between members of the public and policy makers who rarely or never take part in existing consultation processes.

Each Citizens' Panel is designed to fit the specific nature of the topic, the requirements and needs of the institutions involved and the unique characteristics of the chosen locality and its people.

***Citizens' Panels* in the North West**

As part of the ULYSSES project, five exploratory *Citizens' Panels* (CPs) took place between 1996 and 1998 in the North-West region. In total about 40 citizens and 30 policy-makers from the public, private and voluntary sectors took part in 30 sessions (lasting over 70 hours). All CPs participants were recruited within two chosen localities: City of Manchester and St-Helens. For three of the CPs, individuals with similar criteria were recruited –for example, young people (under 24) living within the boundaries of the Longsight ward (City of Manchester). Individuals with a broader mix of criteria –matching as far as possible the structural characteristics of the population living locally- were recruited for the other two CPs. The CPs were asked to discuss climate change, local planning and the environment, quality of life and specific issues like transport.

Apart from the two initial organisations chosen by the research *team (Manchester Local Agenda 21 Forum* and the *Groundwork Trust St-Helens, Knowsley and Sefton*), all the other policy-makers involved were chosen by the participants themselves during the course of their deliberation. The selection was based on the participants' perception of the relevance of policy-makers in relation to the problems addressed by the panel.

Citizens in the North West are concerned about Climate Change

In general, most citizens had noticed changes in the weather through their own life experience. Even if the topics of 'climate change' or 'global warming' did not emerge initially and spontaneously at the top of their daily preoccupations, most of the citizens became increasingly concerned by the issue of climate change as they were presented with information in the course of the Citizens' Panel. The citizens identified some of the possible consequences of global warming for the North West including increasingly erratic weather patterns, sea flooding and water shortages.

'.... in our part of the world, winters were cold weren't they? I can remember every October you got your winter boots out with your heavy clothes and you were in them until March. And I couldn't tell you how long it is since I ever wore fur boots because the winters don't seem as cold do they?'
Denise, 57, retired, Beswick, Manchester

'Well even Southport now, they've had to build a new sea defence haven't they? They are doing it now and they've had to abandon the air show… There used to be an air show every year and thats been stopped by the construction work now to build a new sea defence…'
Dan, 32, van driver, Blackbrook, St-Helens

'Well I heard somewhere, it's not just the water in the reservoirs that's low. There's another source of water that is under the ground and that's low too, and that's going to take years to replace'.
Bob, 43, unemployed, Manchester

'....this season in Jamica, where my sister's boyfriend lives, has been the worst rain they've ever had and people have died'
Josie, 30, nursery nurse, Manchester

Citizens want more environmental education and information but…

When asked what should be done to address climate change, 'more information' was one of the recurring suggestions by nearly all the citizens. As climate change was an inter-generational problem, it was felt that environmental education in schools should be a priority, as it will affect the next generation most of all.

'But before [action is taken by government], they've got to educate people first. They can't just say that there's going to be a ban [on car use] and it's because of global warming! People would say what is global warming?… You've got to educate them first'
Josie, 30, nursery nurse, Manchester

It was also generally felt that the information provided should relate to the citizens' daily life. In their own words, it should be "down to earth", presented in "a simple way", and use "less jargon, like CO_2" so that "ordinary people can understand what's going on and not just scientists and academics". Citizens also expressed serious reservations about over-information and pointed out some of the practical implications of 'information' overload.

'…our electricity bill came in today and there was about half dozen different papers and things, all with it. And you just take them all out, sort the bill and put the rest in the bin'.
Anna, 30, unemployed, Manchester

In some cases, citizens felt that it was the "awareness of government" that "should be raised" about climate change issues.

Citizens' strong sense of 'rights' and 'wrongs' and of fairness

Citizens feelings about climate change were based on a widely-held sense on what was felt to be 'right' or 'wrong'.

'We don't know the why's, and why we want to [act on the issue of climate change],... it's just an instinct of feeling that you want to protect something…'
Susie, 45, student and mother of 3 children, Manchester

Even during the discussion about specific market instruments to address climate change, citizens tended to evaluate them in term of their sense of 'right' or 'wrong' as illustrated in the following quote.

'To me [international CO_2 trading permits are] like somebody who's smoking [and] can't smoke at home… and they go next door and they say "can I smoke in your house, here's a fiver"! I think money's not the answer but I suppose it's such a commercial world that you've got to look at financial solutions. It doesn't feel like the answer. It seems obscene somehow doesn't it?'
Denise, 57, retired, lives in Beswick, Manchester

In general, citizens expressed a strong sense of fairness which meant that everybody had to act responsively and decisively on climate change.

Climate change: global problem, global responsibility

The citizens tended to reject a sense of responsibility defined just at the individual level, however, because of the global scale of the problem.

'When you hear of a problem [like global warming], it would be nice if something could be done, but there's a feeling of helplessness as an individual. With most environmental issues as an individual you feel helpless.'
Bob, 43, unemployed, Manchester

Therefore, the citizens tended to recognise that climate change had to be tackled at a collective level because it is "a global problem, so you need a global solution". Uncertainties about the causes and the consequences of climate change should not be an excuse for inaction.

'Well, it is difficult if you've got two opposing views… I'd always go for caution… If we may need to bring pollution down, then I'd go that way because it can't do any harm, it's got to be better'.
Leo, 66, retired power station employee, Manchester

'…when I was reading about it [climate change], it seemed pretty serious but.. I don't know 'cause you can't really predict what's going to happen. No one really knows, but I mean, government, well all governments seem to be just sort of waiting really to see what will happen and that's probably not the best thing to do.
George, 21, former student, unemployed, Longsight, Manchester

Decisive action from responsible institutions

Many citizens were generally pessimist and fatalistic about the ability –but also the willingness- of institutions to act on climate change. They did, however, also recognise that actions should and could be taken.

Denise:	*[climate change is] very worrying.*
Anna:	*It is very concerning.*
Denise:	*It's unknown isn't it and you can't just stop it, it's going to happen, I don't*

> *think we can stop it, we can't control it.*
> Anna: *Not yet.*
> Bob: *Yes, but you can control pollution.*
> Extract of an exchange during a *Citizens' Panel* in Manchester

Although action could take the form of technological innovations, the citizens generally felt that social and cultural changes were more important.

> *'…I think you've got to change the attitudes of people before you make change. You can change, you know, electric cars and all the rest, but it's the attitudes of people [that matter].*
> Bob, 43, unemployed, Manchester

Generally, the citizens felt that effective action on climate change would have to be initiated by responsible institutions (governments and businesses) in order for citizens to feel motivated to play their part. One way for responsible institutions to be perceived as serious about acting on climate change was to provide sufficient resources for policy responses.

> *'You've got to do it seriously. In order to do it seriously, you've got to spend serious money I think'*
> Joan, 27, machinist, St-Helens

The change of government in 1997 was generally perceived by the citizens as an opportunity for much needed decisive collective action on many issues linked to global and regional environmental issues (like transport). Citizens expressed moderate optimism about (1) the positive impact that greater citizens' involvement could have in the policy-making process, (2) the willingness of the new government to act decisively, and more generally (3) a hope in future generations.

> *'I would like to hope and think that we'd blocked up the hole in the ozone, got decent weather,[and] that because of what we're trying to do now, or hoping that we're going to do now. ... When the hole in the ozone was first discovered everybody did something, now it's dropping back off. Perhaps meetings like this will give it another surge, another push in the right direction on all the different things, and just in general clean up everything so that it comes to a high standard and we maintain it. ..... hopefully we should be able to do it in 20 years'*
> Fred, pub licensee, Billing nr. St-Helens

> *'I think it will improve because people are more aware of things nowadays and there's better education for the ones that are growing up, think it will improve'*
> Mary, 76 former nurse, St-Helens

What does the deliberation of *Citizens' Panels* mean for policy on climate change?

The *Citizens' Panels* organised in the North-West revealed or confirmed several trends which might be relevant and useful for policy-making about climate change. Most notably, policy initiatives should build on:

- the existing strongly-held values of citizens including general concerns for future generations, a moral sense of 'right' and 'wrong' about environmental matters and a precautionary attitude
- a deep longing among citizens for effective, decisive and convincing collective action by responsible institutions
- the willingness by individual citizens to take action if institutions seems firmly committed and if policy initiatives are seen as socially fair and equitable
- the general willingness by citizens to take part in additional deliberative / public participatory processes as long as it leads to tangible results
- the cautious mood for optimism generated by the new government

There were also a few specific policy recommendations:

- increase environmental education (including about climate change) through the school curriculum to generate long-term environmental awareness and support for sustainable policy
- design a sufficient and effective environmental information campaign which avoids the counter-productive effects of information overload.

Public Policy

The public policy response in the North West to climate change has been gaining momentum over the past five years in response to the UK Government's commitments made at the 1992 Rio 'Earth Summit'. The December 1997 Third Conference of the Parties to the Framework Convention on Climate Change at Kyoto in Japan gave a further impetus to develop public policy which has influenced both public attitudes and private actions. The UK Government has a target to reduce emissions of CO_2 by 20% by the year 2010, and a legally binding EU commitment to reduce emissions of a basket of six greenhouse gases (including CO_2, methane and nitrous oxide) by 12.5% on average for the years 2008-2012. In October 1998, the Government announced a consultation process to allocate greenhouse gas emissions between sectors (for details see under consultation papers on DETR's website: http://www.environment.detr.gov.uk).

Other relevant policy developments:

- National Sustainable Development Strategy (currently undergoing consultation on its revision)

- North West 'Action for Sustainability' (about to be launched for consultation)

- Local authorities are obliged to produce Local Agenda 21 strategies outlining the ways in which their communities can address environmental challenges such as climate change through everyday and policy actions; these are due for publication during the year 2000. They are characterised by measures to promote wiser resource use and enhance quality of life and, by implication, involve reductions in CO_2 emissions through such measures as energy efficiency and changes in transport behaviour. There is considerable variation in the way in which this is approached by Local Authorities and the progress which is being made, allied to the fact that the connection between addressing climate change and such non-statutory policy is not always clear.

- More integrative, and to some extent cross-sectoral, thinking is in evidence through the production of Local Environment Agency Plans (LEAPs), Catchment Management Plans and Shoreline Management Plans, which involve the collaboration of public, private and voluntary sector bodies.

Public policy in respect of climate change in the North West is increasingly characterised by an integrative approach to sustainable development. The agenda of sustainable development is becoming infused into the approach of public, private and voluntary bodies, reflected in the suite of strategy documents either completed or being produced and the establishment of new bodies for regional policy making and delivery. The newly established Regional Chamber and the soon to be formed Regional Development Agency, for instance, represent notable advances in the Region's ability to co-ordinate the diverse agenda prompted by sustainable development generally and climate change in particular.

Renewable Energy in the North West, April 1998

County	Source Type	No. of Sites	Capacity DNC[1] (MW)	Generation Elec (MWh)
Cheshire	Landfill Gas	6	9.66	47,357.4
	Other[2]	8		57.0[3]
	Sewage Sludge Digestion	8	0.89	3,394.6
Cumbria	Landfill Gas	1	0.48	n/a
	Other	2	n/a	n/a
	Small Scale Hydro	2	0.34	1,591.7
	Wind Onshore	8	9.54	42,015.6
Greater Manchester	Landfill Gas	2	1.82	2,191
	Other	10	n/a	n/a
	Sewage Sludge Digestion	4	3.28	16,775.1
	Small Scale Hydro	2	1.07	1,696.7
Lancashire	Landfill Gas	3	6.22	26,511.3
	Other	17	n/a	n/a
	Sewage Sludge Digestion	3	0.66	3,734.0
	Wind Onshore	1	1.68	n/a
Merseyside	Landfill Gas	4	1.71	4,793.5
	Other	6	n/a	n/a
	Sewage Sludge Digestion	1	n/a	n/a

[1] Declared net capacity
[2] Includes farm gas, hospital waste, industrial wood and specialised waste combustion
[3] Thermal (MWh)
n/a Not available

Source: ETSU, renewable energy statistics database for the UK

Knowledge Required for Future Policy Development

- **Development of Regional Climate Change Scenarios:** The Scenarios used in this study are derived from models which have a resolution of several hundred kilometres which do not take account of topography such as the Pennines and the Cumbrian Fells. Possible methods to add more detail to these include climate analogues, down-scaling, high resolution nested models - see appendix for details. Expertise exists at Climatic Research Unit (University of East Anglia), Hadley Centre (Meteorological Office) and more locally at the University of Derbyshire.

- **Coastal Zone Management:** There is a demand for more detailed information on the sensitivity of the North West coastline to climate change. The current information has too low a spatial resolution or is too generic to be of direct utility in exploring coastline management options. Several critical regions along the North West coastline could be selected for a more in depth modelling study of the likely changes under different scenarios of climate and other change. Such a study would translate the generic sea-level rise projections to specific locales by combining it with detailed local information on erosion rates, precise shoreline topography, extreme events, sedimentation patterns, sea-water currents, inlets and estuaries, sea-water temperature, etc. It might additionally use historical records as a basis for climate analogue studies: i.e. using the extreme events of the past as an indication of the future. Very little work has been performed on the relationship between increased average sea-level height and the frequency and extent of tidal surges, windspeeds and wave heights. Further development of models to explore the increased probability and scale of extreme tidal events is vital if we are to be able to assess the significance of climate change for coastal protection strategies. The UK centre of expertise on tidal and extreme events and coastline dynamics is located within the North West: the Proudman Oceanographic Laboratory (POL) at Bidston, Birkenhead (a NERC institute). As well as maintaining detailed records of sea-level change, POL researchers are exploring the impacts of climate change upon the height and frequency of storm surge events. They are using data from climate models as inputs into detailed mathematical models of the dynamics of storm surge events. Such pioneering research could be adapted to the specific context of the North West coastline. Models are also being developed at POL and the University of Liverpool which explore the erosion of beaches, overtopping of sea-defences and damage to defences which could be applied to the study of the impacts of climate change. Such modelling could be advanced in the North West in order to attempt to quantify the implications and costs of structural and ecological damage and of beach erosion. Reasonably long-term data is available for some coastal locations, e.g. the Sefton Coast, and for several Ports and Harbours, and this could be developed for use in the local studies. The study would involve a multi-disciplinary team of geohydrologists, ecologists, engineers and geographers, in addition to the stakeholders. A further advantage of such a study is that its findings could feed into the coastal management strategies for the North West which are presently producing detailed Shoreline Management Plans.

Partners who may be interested: Local authorities, the Environment Agency, Ports and Harbours, shipping companies, specific companies, the National Trust, insurance companies, POL, English Nature, RSPB, coastal strategy groups.

- **Upland Management:** The University of Lancaster research on increasing winter river flows and declining summer river flows in the River Lune over the past 100 years raises some important questions about whether such a long-term trend can be explained by land-use change or by climate change or by change in both. It would be helpful for the research to be extended to other river catchments in the North West region. In particular, it would be useful to compare rivers which have experienced similar rainfall patterns, but where the land-use practices have been different, or vice versa, in order to tease-out the relative contributions of climate change and land-use change in explaining change in river flow patterns. Field-based and modelling studies of rates of erosion in different environmental conditions, and given different land-use management regimes (e.g. different patterns of grazing), would also be enormously helpful in attempting to tease out the relative role of climate and other changes. The Institute of Freshwater Ecology (IFE) at Windermere has already done some work on relating lake sediments and land-use practices, which indicates a correlation at the catchment level between grazing levels and lake sedimentation. This work has taken place to date in relation to relatively few upland tarns and could be usefully extended to include climate variables and other lakes in the North West region, for which IFE holds many unique long-term data sets. It may be possible to examine such issues on sites where grazing pressures have been reduced due to specific land-management policy, compared with high-grazing sites. Such sites are in existence, e.g. on land owned by North West Water in the Peak District. Such a comparison would also be useful in order to relate the surface water quality to climatic and land-management variables. The more general issue of how climate change will affect upland vegetation, soils and fauna, and the implications for upland farming, gaming, and recreation, also need to be pursued in future research.

Parties who may be interested: National Trust, North West Water, Moorland Society, Heather Trust, MAFF, Environment Agency, ITE, IFE

- **Impacts of Climate Change on Peat Soils**
  A critical issue identified in the scoping study is the impact of climate change upon peat soils, in particular whether they accumulate or deteriorate under different temperature and rainfall regimes. There are significant implications for the carbon budget of the North West and indeed for the UK (given the extent of peat soils in the region). Detailed empirical and modelling research is required in the North West region to substantiate preliminary findings on these questions.

Parties who may be interested: National Trust, North West Water, Moorland Society, Heather Trust, MAFF, Environment Agency, ITE

- **Impacts on Agriculture and Forestry**
  Change in agricultural crops and practices are likely to follow long-term climate change. Farmers and other land users will require detailed information on the opportunities and risks associated with climate change. This might take the form of demonstration farms and projects throughout the region, drawing upon research into new crops and varieties, farm waste and water management and irrigation technology. Similarly, on-going research into the impacts of climate change upon forest growth, forest management and new end-uses of wood products (e.g. biomass) will need to be applied at the regional level. Again, demonstration projects will be important in providing evidence of tree responses which decision-makers can act upon.

Parties who may be interested: Forestry Commission, Community Forests, MAFF, ADAS, Environment Agency, National Trust, ITE, commercial timber companies, renewable energy interests

- **Lakes, Water Quality and Climate Change:** Lakes appear to be highly sensitive indicators of climate change. A strong signal between the position of the Gulf Stream and the physical, chemical and biological properties of several Cumbrian Lakes has been discovered by George and colleagues at the Institute for Freshwater Ecology (IFE), Lake Windermere (a NERC institute). IFE Windermere is the UK's leading research centre on lakes and it has the best set of long-term records for lakes in the whole of Europe (dating back to the 1930s for Lake Windermere, and to the 1950s for many other lakes). There is much potential for developing IFE's modelling work using its extensive data-sets in order to disentangle the effects on lake properties of human influences from long-term variations in the weather and climate. Such a model could be used to provide predictions of water quality of lakes, which would be useful for water and amenity management (a 'lake forecast' comparable to a weather forecast). (E.g. this could quantify the observation that low winter rainfall, combined with extended periods of high pressure weather in spring and summer is likely to create a problem of water quality due to algal blooms). A lake model can inform the assessment of water supply and quality problems and can help in the development of mitigation options. The North West contains an interesting range of lake types (from nutrient rich lakes such as Esthwaite, to nutrient poor lakes such as Wastwater, and from deep lakes to the shallow meres of Cheshire). The wide variety of lakes could be used as indicators of climate change. Models could also be used to explore the interaction of lakes and surrounding ecosystems (e.g. wetlands and woodlands).

  Partners who may be interested: North West Water, other water companies, Lake District National Park, NERC, Environment Agency, English Nature, the National Trust, IFE

- **Impacts of Climate Change on Regional Manufacturing Industry:** Several issues have been illuminated in the. scoping study which have not previously received much attention in climate change impacts research There may be a case for a more detailed quantitative study of the impacts of climate change on: **cooling systems** and the costs of adapting existing plant to be able to cope with higher summer air temperatures; investigation of **work conditions in hot summers**, the costs to employers incurred by such conditions, employee perceptions, changes in work practices, and management options; and the implications of a change in rainfall patterns for the abstraction of input water and the management of on-site waste water.

Partners who may be interested: Industry associations (e.g. CBI, CIA), specific companies, HSE, trade-unions.

- **New COMAH Regulations on Major Accidents and Hazards**: Another possible route for exploring climate change issues is the introduction of the new Control of Major Accidents and Hazards (COMAH) regulations, concerned with contingency planning for major accidents and crises. HSE and the

Environment Agency have joint responsibility for the implementation of COMAH regulations. Extreme weather events - such as extreme storms, hurricanes, tidal surges, etc. - would be important issues to include in any contingency planning. The concentration of chemical and related industries on the Mersey Estuary and Wirral would be a good case-study. This could draw upon coastal-zone management research suggested above, e.g. using estimates of the return periods of flood events under different climate change scenarios.

Partners who may be interested: as above and also for coastal-zone management

- **Leisure and Tourism and the Weather:** Whilst there is a wide-spread belief that the weather has a major influence on the extent and type of leisure and tourist activities in the North West, there is very little empirical evidence on the subject. A more detailed study could provide some more detailed information on: tourist perceptions and leisure purchaser's expectations concerning the weather (e.g. through surveys, interviews, discussions with tourists and providers). Some statistical analysis may be possible, e.g. a correlation between the extent and type of leisure / tourist activities and weather conditions could be mapped out. Such tools, properly developed, would help in the forecasting of visitor numbers under different climate change and socio-economic scenarios.

Partners who may be interested: North West Tourist Board, Cumbrian Tourist Board, major tourist and leisure companies, the National Trust

- **Impacts on the Regional Economy:** can be explored through the use of economic models such as input-output models, which aim to describe the interconnections within an economy in terms of 'multiplier effects'. For instance, farmers may rely upon feedgrain in livestock production. Each unit of livestock production may then contribute to further economic activity, for example in meat processing and packaging. Hence, the impacts of climate change upon the price of feedgrain affect not only livestock production but also the down-stream economics of meat packaging. Input-output models aim to describe the down-stream economic impacts in quantitative terms. An example of the use of input-output models in assessment of the impacts of climate change is provided by the 'MINK' study supported by the US Department of Energy. Similar regional economic models could be developed for the North West region in order to quantify the integrated effects of climate change upon different economic sectors.

Partners who may be interested: North West Regional Chamber, North West Regional Development Agency, DETR

- **Climate Change Indicators and Reporting:**

  The Scottish Environmental Protection Agency (SEPA) has proposed a set of climate change indicators to measure Scotland's climate change profile and to assess progress towards reducing its vulnerability to climate change as well as its contribution to global warming. The North West Regional Chamber might wish to establish a similar list of indicators, drawing upon the following criteria:

- Greenhouse gas emissions, preferably broken down by sector and gas (CO_2 CH_4, N_2O, HFCs, HCFCs and SF_6)
- Sinks for CO_2, particularly forests and peat soils
- Measurements of ambient CO_2
- Long-run air temperature records for upland and lowland sites
- Long-run rainfall records for upland and lowland sites
- River flow data
- Sea temperature data
- Sea level records
- Number of gale warnings as an index of 'storminess'
- Frequency and height of storm surges
- Renewable energy generation
- Energy efficiency/reductions in CO_2 and other greenhouse gases by sector/company
- Species and habitats including flora and fauna in both upland and lowland sites

Companies in the North West region might wish to include in their Environmental Reports an assessment of the direct and indirect impacts of climate change upon their operations and future business. There are a number of practical approaches they might take:

1. Calculate their greenhouse gas emissions - especially CO_2 but also methane, nitrous oxide, CFCs, HFCs, HCFCs, SF_6, etc. - and produce targets for their reduction over time (as some do already, though this information is rarely presented on a regional basis).
2. Assess the direct impacts of climate change upon their activities, and examine possible environmental management solutions.
3. Produce water and energy efficiency and conservation strategies and targets.
4. Be sensitive to the sources of inputs and supplies to ensure that vulnerability to climate change is taken into account (i.e. include climate change considerations in environmental supply chain management).
5. Identify possible business opportunities arising from

climate change, especially from policy measures to reduce CO_2 and other greenhouse gas emissions. This will require innovative solutions in terms of energy efficiency & conservation, renewable energy generation (wind, solar, biomass, CHP, etc.), more energy efficient equipment and processes, new building materials and methods, new agricultural and forestry opportunities and tourism and leisure markets.

Ongoing Research

In addition to the above suggestions, some related research is already underway, including:

- more detail on climate vulnerability, ecological impact, risk assessment and response options in the areas of agriculture, biodiversity, coastal domain and hydrology in the North West and East Anglia (funded by MAFF, DETR and UK Water Industries Research).
- mitigation of climate emissions, to meet the UK's commitment to the Kyoto targets. Examples include the ESRC-funded 'carbon flow' research on Greater Manchester, and the ongoing renewable energy programme of United Utilities plc and Pilkingtons plc.
- integration of climate objectives with regional policy in general, including economic development, urban regeneration, public services and environmental protection. Examples include the "Integrated Visions for a Sustainable Europe" project. This is developing the UK's first fully interactive regional comprehensive model, linking environment-economy systems, spatial mapping and a highly user-friendly interface for priority choice and policy design.

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Appendix: The UKCIP98 Climate Scenarios for the North West of England

The UK Climate Impacts Programme published new scenarios of climate change in the UK in October 1998. This appendix draws upon the UKCIP scenarios in providing a more detailed interpretation of future climate change in the North West of England. The UKCIP scenarios contain four alternative climate futures termed '**Low**', **'Medium-low'**, **'Medium-high'** and '**High**'. It is not possible to quantify the relative probabilities of each of the four UKCIP98 scenarios occurring and all four possibilities should be evaluated in a full risk-assessment exercise[1]. The impact and significance of climate change for the North West, for example, would be quite different if UK climate looked like the **Low** scenario rather than the **High** scenario in a hundred years time. Nevertheless, since the **Medium-high** scenario is based on a 1 per cent per annum growth in greenhouse gas concentrations, a growth that approximates the IS92a emissions scenario which has been widely used as a 'best guess' emissions profile, it is not unreasonable to use this scenario if only one were to be used.

The rate of future climate warming in North West England for these scenarios ranges from 0.9ºC per century for the **Low** scenario to 2.6ºC per century for the **High** scenario. For comparison, mean temperature at Manchester Airport during the most recent decade - 1988-1997 - has been 0.45ºC warmer than the 1961-90 average, a warming rate that if continued would amount to 2.65ºC per century. This is at the upper end of the future scenario range, although this rate of regional warming has not yet been sustained for more than two decades. The warming in the UKCIP98 scenarios for the North West is slightly more rapid in summer than in winter. In winter, minimum temperatures rise more rapidly than maximum temperatures reducing the diurnal temperature range, whereas in summer the opposite occurs.

Before commenting on the UKCIP98 precipitation change scenarios it is important to emphasise the substantial variation in 10-year or 30-year averaged precipitation totals that can occur quite naturally. For the North West, 30-year annual precipitation totals can vary naturally by up to ±5 per cent or more, while winter or summer totals may vary naturally by as much as ±15 per cent. These levels of natural variability may pose as great a challenge to water management in the region as is presented by the human-induced changes summarised below.

Annual precipitation increases in all four UKCIP98 scenarios, by between 3 and 5 per cent by the 2050s, but this is made up of precipitation increases in autumn and winter, decreases in summer and little change in spring. Winter precipitation increases over North West England by between 6 and 14 per cent by the 2050s, whereas summer precipitation decreases by between 1 and 10 per cent by the same period. All of these changes are with respect to the 1961-90 average.

Evaporation in the North West increases in all scenarios and seasons, except in winter in the early decades of next century. Potential evapo-transpiration (PE) increases by up to 10 per cent in summer by the 2050s and up to 20 per cent in autumn. Annual PE increases by about 10 per cent by the 2050s under the **Medium-high** scenario.

Changing Probabilities of Seasonal Climate Extremes for the North West

Percentage of Years with Annual Temperature in the North West Exceeding the Warmth of 1997 for Four UKCIP Scenarios

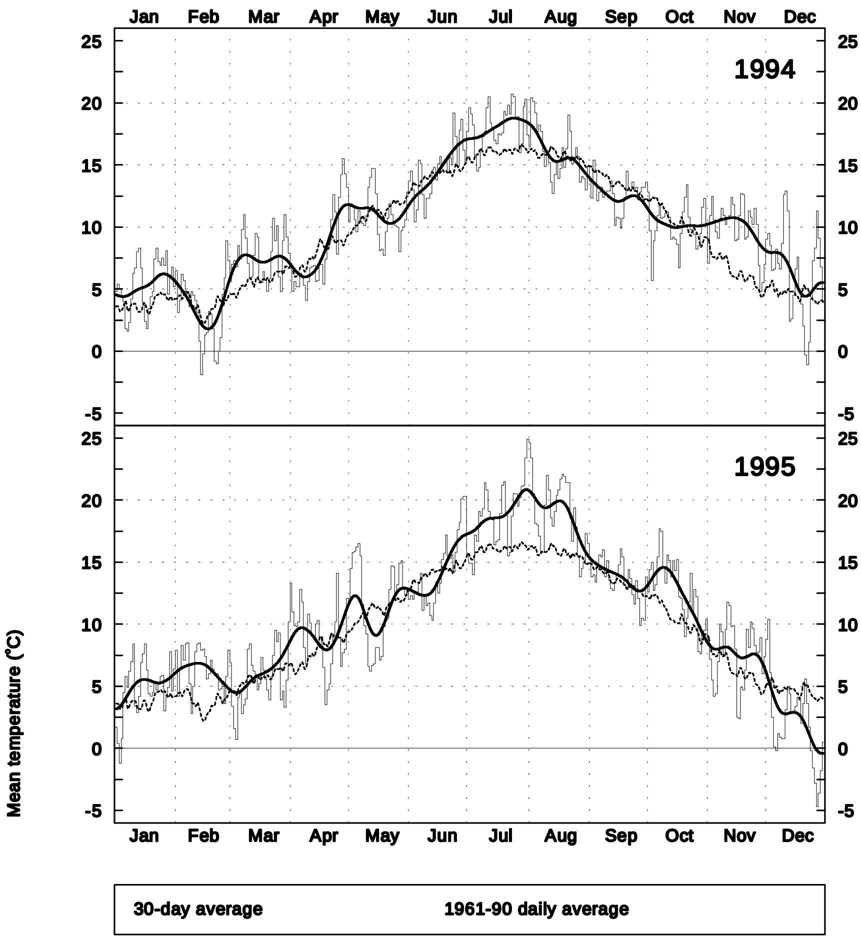
	1961-90	2020s	2050s	2080s
Low	5	9	23	48
Medium-low	5	41	69	88
Medium-high	5	58	87	99
High	5	65	91	99

Percentage of Years Experiencing Certain Climate Extremes in the North West for the *Medium-High* Scenario

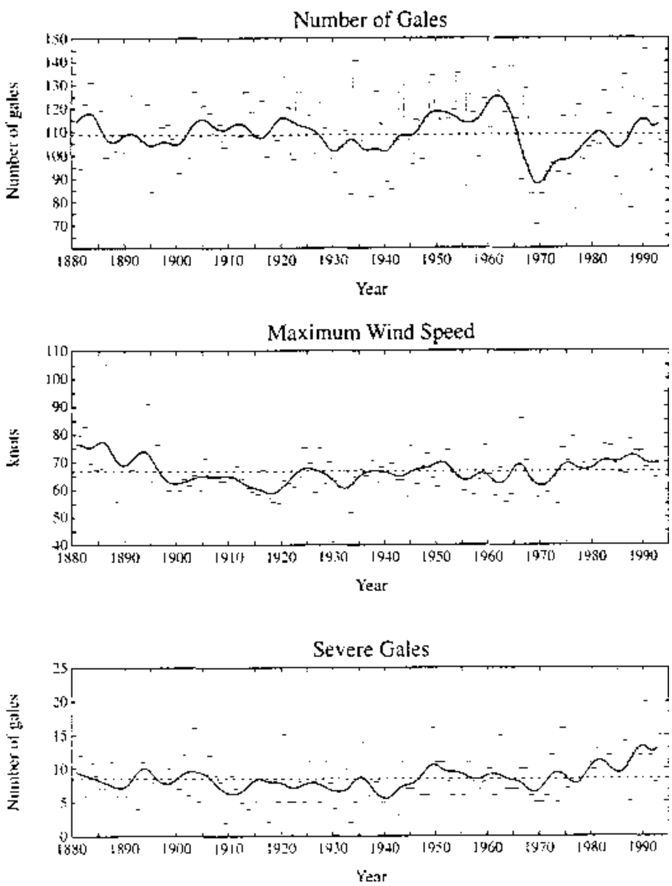
	1961-90	2020s	2050s	2080s
Mean temperature				
A hot '1997-type' August (+3.4C)	1	9	21	27
A warm '1997-type' year (+1.06C)	5	58	87	99
Precipitation				
Summer precipitation <50% average	<1	2	8	2
Two-year precipitation <90% average	11	3	7	3

[1] Below we discuss the possibility of climate changes occurring outside this band of scenarios.

Daily Central Temperature 1994 - 1995 (source: Hulme & Barrow, 1997)



Gale Index for the Northern British Isles (source: Hulme & Barrow, 1997)

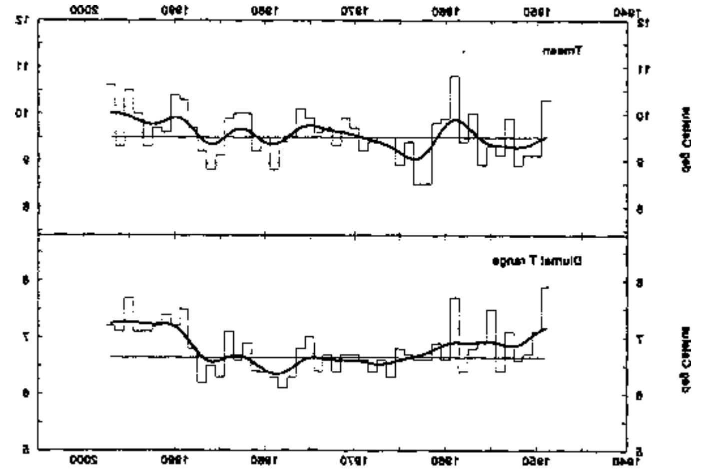


The main difference compared to southern England is that August's do not warm as rapidly, summer drought frequencies increase (but not as rapidly as for southern England), and that the likelihood of 24-month droughts decreases more rapidly than for southern England.

Putting Climate Change Scenarios in the Context of Recent Trends and Anomalies

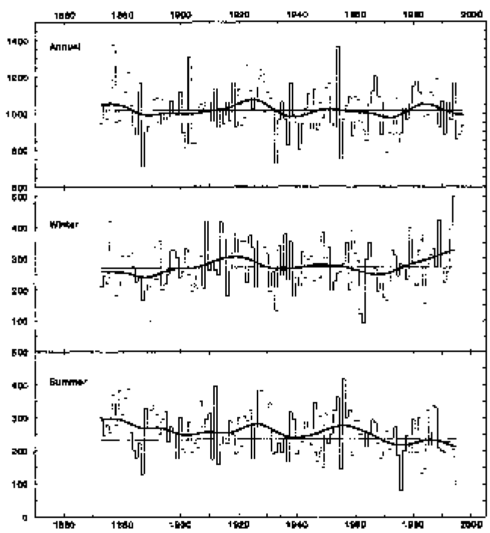
We show the results of two analyses that depict recent trends in temperature and precipitation in the North West. The figure below shows the record of annual mean temperature and diurnal temperature range at Manchester Airport from 1949 to 1997[2]. Annual mean temperature has been rising since the 1960s at this site and four of the six warmest years have occurred since 1989. This series forms the basis of the claim above that temperatures at Manchester have been rising in recent decades at a rate that is towards the higher end of the scenario range for next century. The diurnal temperature range has also increased in recent years, although not beyond levels encountered in the 1950s. Nevertheless, the diurnal range has averaged nearly 1ºC more than prevailed during the 1960s and 1970s.

Trends in annual mean temperature (top) and diurnal temperature range (bottom) for Ringway Airport 1949-1997. Smooth curves show 10-year smoothed data and horizontal lines show 1961-90 average



We also show an analysis of region-wide precipitation trends since 1873. Annual precipitation has displayed no long-term trend over this period, whereas summer precipitation has fallen by up to 20 per cent. There has been a slight compensating increase in winter precipitation with the winter of 1994/95 being the wettest across the region since 1873.

Trends in annual (top panel) and seasonal (bottom two panels) precipitation for the North West region 1873-1997. Smooth curves show 30 year smoothed data and horizontal lines show 1961-90 average (source P.D.Jones, pers.comm.)



[2] There are other, longer temperature series available in the North West, although these have not been accessed in this study. The Central England Temperature series discussed in the UKCIP98 climate scenario report is largely representative of North West England.

The summer of 1995 was the second driest. Not all of these annual and seasonal variations in precipitation are necessarily natural in origin, although human influence is only likely over the most recent decades. The 10-year and 30-year levels of natural variability in these precipitation series are therefore quite large.
We next provide an illustration of what these UKCIP98 climate changes would mean for the North West by examining two recent extreme seasonal climate anomalies - the summer of 1995 and the winter of 1989/90. The summer of 1995 was the equal warmest recorded at Manchester Airport (along with 1976) with an anomaly of 2.3ºC above the 1961-90 average. Across the North West as a whole the summer averaged 1.8ºC above the 1961-90 average. This summer warmth equates to the *average* summer to be expected by the 2050s under the UKCIP98 **Medium-high** scenario, i.e., five summers in ten by the 2050s will be warmer than the 1995 summer. An extreme summer, however, by the 2050s will be considerably warmer than this and the Figure below shows one example for, say, the summer of 2054. Here, the regional anomaly is 4.7ºC above the 1961-90 average and 2.9ºC warmer than the 2050s average, i.e., the summer of 2054 would be more extreme relative to the prevailing 2050s climate than the summer of 1995 was extreme relative to the average 1961-90 climate.

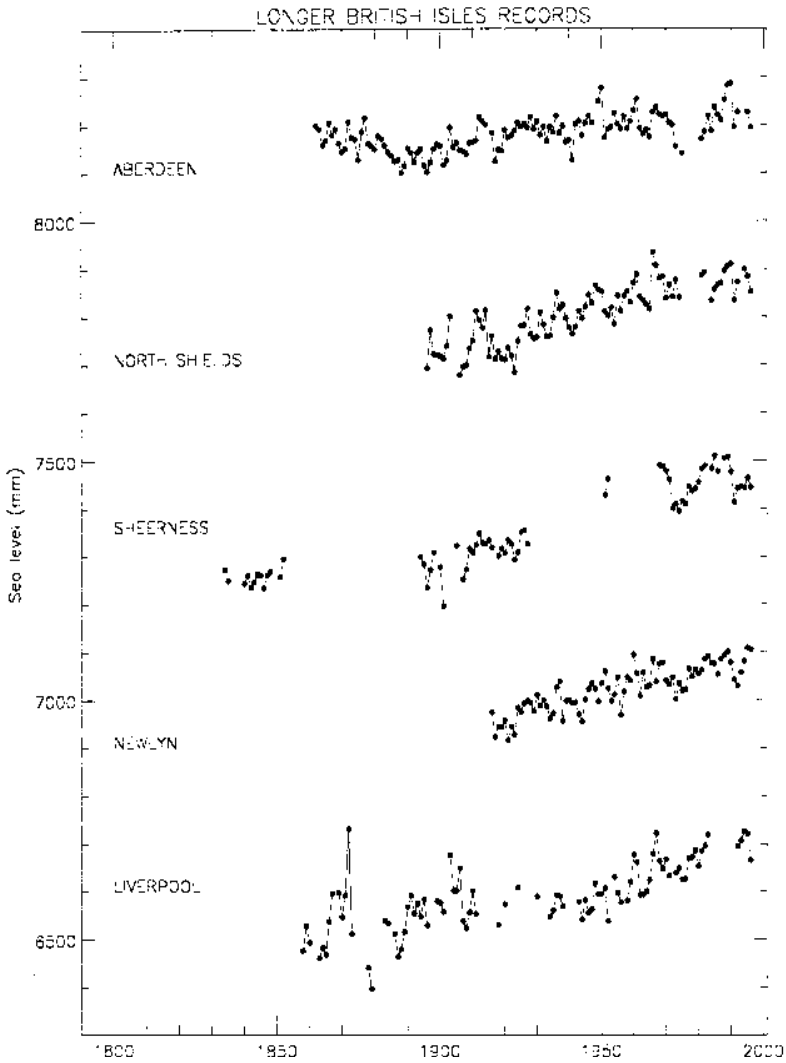
We can repeat the exercise for the mild winter of 1989/90. At Manchester Airport this winter was 1.8ºC above the 1961-90 average, compared to a region-wide anomaly of 1.7ºC. Again, by the 2050s half of all winters will be at least as mild as this, but some individual winters will be much milder still. Thus, for example, the winter of 2050/51 would be 3.5ºC milder than the 1961-90 average and 1.7ºC milder than the prevailing 2050s climate. In this case the anomaly for this winter relative to the 2050s average is similar to the relative anomaly of the 1989/90 winter.

The two seasonal extremes chosen above were also quite unusual in regard to precipitation. The 1995 summer was exceptionally dry - only about 50 per cent of average summer rainfall - although not quite as dry at Manchester Airport as in 1976. The 1989/90 winter was wet - about 33 per cent above the 1961-90 average - but not as wet as 1994/95. The climate modelling studies upon which the UKCIP98 scenarios were based suggest that hot summers and mild winters in the future will be associated with the same precipitation anomalies as observed - the hot summer of 2054 was dry and the mild winter of 2050/51 was wet - but that these future seasonal precipitation extremes will *not* exceed the anomalies observed in the most recent extreme seasons. This implies that in rainfall terms, although the average summer (winter) precipitation may decrease (increase) by a few per cent as summarised above, the extreme seasonal precipitation anomalies may not be more extreme than those recently observed. Nevertheless, with higher levels of evaporation in the future the effective summer precipitation may indeed be less than recent seasonal extremes.

<u>Sea-level Rise</u>
One of the most likely consequences of climate warming is a rise in mean sea-levels. This would occur primarily because warmer ocean water will expand and also because of melting of land glaciers. The figure below shows trends in measured sea-level around the UK coast over the last 100 years have been studied, including the site at Liverpool. All of these series show a rise in sea-level, the rise at Liverpool being about 12.3 cm/century when calculated over the full record since 1858. The rate of rise has been slowly accelerating at Liverpool, however, amounting to 13.9 cm/century if only data from 1900 are used. These raw sea-level measurements need to be adjusted to account for natural rates of emergence or subsidence of the land, these being isostatic adjustments from the last glaciation. For the Mersey region the above figures need reducing by about 1.8 cm/century since the coastline in this region is gradually subsiding. The net unexplained change in sea-level for Liverpool is therefore a sea-level rise of 12.1 cm/century over the present century.

The UKCIP98 scenarios include estimates of future global-mean sea-level rise. These estimates range between 12 cm and 67 cm of further climate-induced sea-level rise by the 2050s, with the **Medium-high** scenario generating 25 cm. This latter estimate would translate into a rate of 31.2 cm/century, a rate that is more than twice the observed rate at Liverpool over recent decades. A further concern about sea-level rise involves changes in storminess combined with high-tides leading to much shorter return periods for certain magnitude high tide-levels. The UKCIP report did not take into account storminess changes, but they did provide one example - although for Harwich in eastern England - of how return periods of high tide-levels may change. The rise in mean sea-level mentioned above (25 cm by the 2050s) could convert a high tide-level with a current return period of 100 years into one that recurs on average every 10 years. This example cannot be translated to other coastal environments because local factors differ so much. *What is warranted, however, is more specific work in the North West on how mean rises in sea-level may alter the levels of risk different parts of the coastline are exposed to.*

Relative changes in sea-level over the last 100 to 150 years as recorded by tide gauges at five UK locations.Last year of data is 1995 or 1996 and units are mms. Data are unadjusted for crustal movements (source: Woodworth et al, 1998).



Daily Temperature Extremes

The UKCIP98 scenario report said relatively little about changing frequency of daily temperature extremes. The only relevant maps were ones that showed changing numbers of degree days above and below certain thresholds. Thus, by the 2050s under the **Medium-high** scenario, degree days with maximum temperature above 25ºC approximately doubled, whereas degree days with minimum temperature below freezing reduced by about 65 per cent.

We can use the SPECTRE model to extract some more specific estimates of changing daily temperature frequencies for Manchester Airport. The average number of 'hot' days (days with Tmax above 25ºC) increases by between 33 and 83 per cent by the 2050s, while the number of freezing winter nights decreases by between 18 and 54 per cent. Individual years will greatly exceed these average figures, thus during the warm year of 1995 there were no less than 31 days with Tmax above 25ºC at Manchester Airport. Individual warm years and summers in the future will generate an even larger number of hot days.

Average annual number of days at Ringway with daily temperatures exceeding the stated thresholds

	Tmax>25ºC	**Tmin<0ºC**
1961-90 climate	6	39
2050s		
Low	8	32
Medium-low	9	27
Medium-high	10	22
High	11	18

Daily Precipitation Extremes

We have looked at recent changes in high intensity precipitation events for the four NW sites using BADC data for 1961-95, but find recent increases only in winter.

What About Surprises?

The UKCIP98 climate scenarios have been derived from climate models that include the best possible representation, consistent with current understanding and computing limitations, of processes in the atmosphere, ocean and land that will determine future climate change. However, we do not understand the climate system well enough to be able to rule out other scenario outcomes. It has been suggested, for example, that relatively rapid climate change could occur if the climate system shows a non-linear response to increased greenhouse gas concentrations.

The most likely example of this is the thermohaline circulation (THC) of the world's oceans, a circulation that is driven by changes in water density related to temperature and salinity. Associated strong ocean currents transport large amounts of heat around the world. The THC brings warm subtropical water into the North Atlantic and this water warms the atmosphere, keeping North West Europe, and particularly the British Isles, much warmer than they would otherwise be. It has been suggested for some time that a collapse of the THC in the North Atlantic could slow the rate of climate warming, or even cause cooling, over North West Europe. How likely is this?

Climate models show that increased greenhouse gas concentrations are likely to reduce the formation of dense cold water at high latitudes in the North Atlantic ocean. Under these conditions the THC would weaken and could eventually, if it collapsed, reduce the surface warming over western Europe by up to several degrees Celsius. The Hadley Centre model, in common with some others, shows a slow weakening of the THC as greenhouse gas concentrations increase. It is important to realise, however, that the cooling due to this effect will only partially offset the general warming from the increases in greenhouse gases. The North Atlantic region will still warm, but parts will warm at a slower rate than if the THC had remained constant.

A sudden, complete collapse of the THC has not yet been seen in any experiment using comprehensive climate models. It seems unlikely that such a collapse would occur in the next few decades and therefore very unlikely that cooling relative to today's climate would occur for a region like the North West of England over this time-scale. If such an outcome were to be included, however, in an impacts assessment as a low probability, high-risk outcome, then parallel high-risk outcomes at the other end of the scenario range (e.g. warming rates of 0.4º or 0.5ºC per decade caused by unforeseen positive feedbacks with the biosphere) should also be included.

Another area for concern lies in the behaviour of the West Antarctic Ice Sheet (WAIS). It is possible that a more rapid rise in sea-level than suggested in our scenarios could occur should the WAIS begin to disintegrate. The WAIS is grounded below sea-level and is therefore potentially unstable. If it were to disintegrate completely, global sea-level would rise by about five metres. Due to the complexity of processes determining the stability of the WAIS predictions are difficult and uncertain. The most likely scenario appears to be one in which the WAIS contributes relatively little to sea-level rise in the twenty-first century, but over following centuries higher discharge rates from the ice sheet increase its contribution to sea-level rise to between 50 and 100 cm per century.

The Hadley Centre is currently actively working to improve our understanding of the climate system and to identify as early as possible any mechanisms that might lead to rapid, non-linear, climate change.

<u>On Levels of Confidence in Climate Change Scenarios</u>

The existence of uncertainties does not imply the absence of knowledge. There are some aspects of future climate change we may have greater confidence in than others. The Table below lists a number of the variables used in this Report in descending order of confidence we may have in the future changes described here. This list is a matter of judgement and formal levels of confidence cannot be applied. Nevertheless, they indicate that we are more confident about increases in carbon dioxide concentrations and sea-level than we are about increases in storminess or intense precipitation. Such an evaluation may be useful in an impacts assessment when trying to interpret the effects of different sources of uncertainty on the range of impact indicator outcomes.

List of Climate and Associated Variables, Ranked in Decreasing Order of Confidence

High
Atmospheric carbon dioxide concentration
Global-mean sea-level
Global-mean annual temperature
Regional seasonal temperature
Regional temperature extremes
Regional potential evapotranspiration
Regional seasonal precipitation and cloud cover
Storminess
Daily precipitation regimes
Changes in climatic variability
Low

It is harder to quantify the relative probabilities of each of the four UKCIP98 scenarios occurring. The Medium-high and Medium-low scenarios relate to different levels of future anthropogenic forcing, either 1 or 0.5 per cent per annum growth. The 1 per cent per annum forcing upon which the Medium-high scenario is based approximates the IS92a emissions scenario, which has been widely interpreted as a 'best guess' emissions profile. In fact, all of the IS92 emissions scenarios were non-intervention scenarios and were based on different assumptions of population and economic growth and on different energy futures. The new set of emissions scenarios being prepared for the IPCC (the SRES98 scenarios) are also all non-intervention scenarios and the range of their greenhouse gas forcing profiles ranges from about 0.4 per cent per annum growth to about 1.2 per cent per annum. Whether or not one sees these emissions profiles as equally likely, it is quite clear that our Medium-high and Medium-low scenarios do span a reasonable range of the possible future climate outcomes that is due to different anthropogenic forcing. As such, both outcomes should be considered in an impacts assessment.

Our Low and High scenarios relate to different values of the climate sensitivity, either 1.5ºC or 4.5ºC (and a IS92a emissions profile). Again, *we cannot at present attach probabilities to these Low and High outcomes, but simply accept that they do represent possible climate futures for the UK, possibilities that need to be evaluated in a full risk assessment exercise. The impact and significance of climate change for the UK would be quite different if UK climate looked like the Low scenario rather than the High scenario in a hundred years time. We believe it is a useful exercise to try and quantify this difference.*

Climate Change Scenarios – 'Downscaling' Methodologies

<u>The Feasibility of Downscaling Studies in Northwest England</u>

The climate scenario information in the UKCIP98 scenarios is depicted at the same spatial scale that is resolved by the HadCM2 climate model, namely 2.5º latitude by 3.75º longitude. The North West region straddles two of these gridboxes. Each of these model gridboxes represents tens of thousands of square kilometers, within which there is a large amount of spatial variability in climate. This coarse resolution of GCM-based scenarios is clearly therefore at first sight a major limitation in their application to a wide range of impacts assessments. These assessments may either be quite localised - around a single river catchment or urban area - or may operate on a national scale, but with a spatial resolution of kilometers or tens of kilometers rather than hundreds of kilometers - for example a national land use classification assessment. How can we get more detailed regional scenario information for use in such impacts assessments? The answer to this question requires some consideration of the problem of 'downscaling' climate change information. A full downscaling analysis for the North West is beyond the scope of this study, but we suggest some ways this may be tackled in the future.

Simple Downscaling Methods
One of the crudest ways of adding spatial detail to GCM-based climate change scenarios is to combine GCM-scale changes with observed climate information. This may be done using mean monthly climatologies at a fine resolution or can be done by simply perturbing an observed monthly or daily time series by the GCM-based changes. The various UKCIP98 scenario changes for different time-slices are smoothed using a simple normal filter and then added to the 10' UK 1961-90 mean monthly climatology to yield climatologies for the 2020s, 2050s and 2080s at the resolution of the baseline climatology. This approach assumes that future spatial climate patterns are similar to the present. This very simple approach to downscaling is easy to apply and does allow impact assessment models to use climate change scenarios at a resolution that would otherwise be difficult or costly to obtain.

Dynamical Downscaling Methods
Another downscaling option is to use a higher resolution limited-area model (often called a Regional Climate Model-RCM) to generate the climate change scenarios at the required resolution. Such regional climate models would typically cover an area the size of Europe, have a spatial resolution of about 30-50 km and be forced by boundary conditions taken from the GCM for one particular time-slice in the present and one in the future. This approach has been adopted by a number of modelling centres around the world including the Hadley Centre. Figures 39 and 40 of the UKCIP report on climate scenarios show the difference in the response of mean winter and summer temperature and precipitation over the UK when modelled by the HadCM2 global model compared to the results from the Hadley Centre regional model, a 50 km model. This analysis is for the Medium-high scenario, but for the 20-year period 2080-2100 (not quite the same as the 2080s period used earlier in this Report).

The broad patterns of response are similar between the two models with the temperature warming greatest in the southeast and least in the northwest (Figure 39) and with winter showing wetting everywhere and summer showing wetting in the north and drying in the south (Figure 40). It is also possible from these plots to see some of the influences of the higher resolution geography of the regional climate model results. Thus the effect of the English Channel can be seen in dampening the winter and summer warming rates and local heating over the Scottish mountains in winter can be seen in the RCM output. For precipitation, the regional model shows greater wetting over the Scottish Western Isles than over the eastern lowlands of Scotland, a difference totally missing in the GCM output.

Just because results from RCM experiments show greater spatial detail than GCMs, including the appearance of sensitivity to more realistic geography, does not automatically qualify them as more 'accurate' than scenarios based on GCMs. There are several acknowledged limitations to the regional climate modelling approach. RCMs still require considerable computing resources and are as expensive to run as a global climate model. Most importantly, the RCM is completely dependent upon the boundary conditions extracted from the GCM experiments to drive the regional atmosphere. In one sense, regional climate model output can only be as good as the global climate model that drives it. It is also worth noting that regional climate model output even at 50 km resolution is still not adequate for some impacts assessments. In such cases as a small river catchment or simulating agriculture or land use at 1 km or 10 km scales there will still be a need for some other form of downscaling, even of regional model output.

Statistical Downscaling Methods
Because simple combination of coarse-scale GCM scenarios and fine-scale observed climate data does not allow for the dynamics of large-scale/small-scale interactions and because regional climate models are slow and expensive to run, a third series of approaches to the downscaling problem have been developed for scenario applications. These approaches may conveniently be grouped together as statistical downscaling methods. There are at least three broad clusters of methods within this general category - regression methods, circulation typing schemes, and stochastic weather generators. We will say a few words about each in turn. It is worth noting, however, that developing a statistical downscaling model is usually quite time-intensive and will *always* require very extensive observational data - daily/hourly weather data, for the surface and maybe for the upper air, and usually for several/many sites or gridboxes covering the region of interest. It need not necessarily be a cheaper or easier option than running a regional climate model. It should also be noted that most downscaling methods and models are developed with a specific application in mind - whether agriculture, forestry, water, etc. - and quite often for a specific geographic region. Not all downscaling methods can easily be transported from one region to another.

Regression methods. These approaches generally involve establishing linear or non-linear relationships between large-scale (e.g. synoptic or gridbox scale climate) and small-scale (e.g. site) climate variables. These relationships are trained on observed data over some suitable period of time, before the resulting equations are 'forced' by large-scale climate output from a GCM experiment to derive the small-scale climate change scenario. Predictor variables typically include large-area average surface temperature and precipitation and upper air geopotential temperatures and heights.

Circulation typing. Circulation-based downscaling methods usually involve relating site or small-scale climate data to a synoptic weather/circulation classification scheme. These classification schemes may be objectively or subjectively determined. One of the most widely used in UK downscaling studies is the Lamb synoptic classification. As with regression-based methods, once these relationships are determined from observed data, the relationship may be used with a daily classification series derived from a GCM experiment. One attraction of these circulation-based methods is that they are based on the well established linkages between synoptic circulation and local weather statistics, such as the probability of a wet day.

Stochastic weather generators. Weather generators (WGs) are another way of constructing site specific or small-scale climate change scenarios, although they rely on a slightly different approach from other statistical downscaling methods. A weather generator is calibrated on an observed daily weather series over some appropriate period, usually for a site, but possibly for a catchment or a small gridbox. The generator is then capable of generating, stochastically, an infinite series of daily weather for the respective spatial domain, this series possessing - in theory - the correct lower and higher order climate statistics for that domain. The parameters of the weather generator then need to be perturbed using output from a GCM for the generator to yield synthetic daily weather under the climate change scenario. To derive the appropriate WG parameter perturbation from the coarse-scale GCM, one of the above two downscaling methods may be employed. One of the weaknesses of weather generators is that because they are stochastically based, they do not always capture the low frequency variations in climate that may be quite important for certain impacts applications. Appendix 8 of the UKCIP report on climate change scenarios provides links to one commonly used public domain weather generator in the UK.

On the use of Historical Analogues in Climate Change Impacts Assessments

Analogue scenarios are constructed by identifying recorded climate regimes which may resemble the future climate in a given region. These records can be obtained either from the past (temporal analogues) or from another region at the present (spatial analogues).

Temporal analogues make use of climatic information from the past as an analogue of possible future climate. They are of two types: palaeoclimatic analogues based on information from the geological record, and instrumentally based analogues selected from the historical instrumental record, usually within the past century. Both have been used to identify periods when the global (or regional) temperatures have been warmer than they are today. Other features of the climate during these warm periods (e.g. precipitation, windspeed), if available, are then combined with the temperature pattern to define the scenario climate. This can provide a potentially rich data set of observed, and therefore physically plausible, climate (thus satisfying criteria 2 and 3).

Palaeoclimatic analogues are based on reconstructions of past climate from fossil evidence, such as plant or animal remains and sedimentary deposits. Three periods have received particular attention: the mid-Holocene (5000 to 6000 years BP [*]) - when northern hemisphere temperatures are estimated to have been about 1°C warmer than today, the Last (Eemian) Interglacial (125000 BP) - about 2°C warmer, and the Pliocene (three to four million years BP) - about 3-4°C warmer. During these periods, global temperatures relative to present conditions may have been similar to changes anticipated during the next century (fulfilling, in part, criterion 1).

Instrumentally-based analogues have been used to identify past periods of observed global-scale warmth as an analogue of a greenhouse gas induced warmer world. Scenarios are often constructed by estimating the difference between the regional climate during the warm period and that of the long term average or that of a similarly selected cold period. An alternative approach is to select the past period on the basis not only of the observed climatic conditions but also of the recorded impacts. A popular example is the dry 1930s period in central North America, which was a period of great hardship coinciding with a depressed economy and widespread soil erosion. It has been adopted in several studies as a possible analogue of future conditions. For instance, in the Upper Midwest very dry conditions were accompanied by mean temperatures some 1°C warmer than the 1951-1980 baseline.

The major disadvantage of using temporal analogues for climate change scenarios is that past changes in climate were unlikely to have been caused by increasing greenhouse gas concentrations (criterion 1). Palaeoclimatic changes were probably caused by variations in the Earth's orbit around the Sun. Changes in the instrumental period, such as the 1930s drought in North America, were probably related to naturally occurring changes in atmospheric circulation. There

[*] BP = Before Present

are also large uncertainties about the quality of the palaeoclimatic reconstructions. None are geographically comprehensive, some may be biased in favour of climatic conditions that preserved the evidence upon which they are based, and the dating of material (especially in the more distant past) may not be precise. In addition, they represent the average (often only seasonal) conditions prevailing in the past. It is rare for them to yield concrete information on the variability of climate or frequency of extreme events. Moreover, given that most temporal analogue scenarios (with the exception of the earliest and poorest quality palaeoclimatic analogues) lie towards the low end of the range of anticipated future climatic warming, scenarios based exclusively on analogues may violate criterion 4, as they do not reflect the range of possible future conditions.

Spatial analogues are regions which today have a climate analogous to the study region in the future. For example, Bergthórsson *et al*. (1988) used northern Britain as a spatial analogue for the potential future climate over Iceland. In this way, modelled estimates of the effects of climatic warming on grass growth in Iceland, based on extrapolation of local relationships, could be compared against the present-day response of grass to temperature and fertilizer application in Britain. The approach is severely restricted, however, by the frequent lack of correspondence between other important features (both climatic and non-climatic) of the two regions (for instance, the daylength in the summer is shorter in northern Britain than in Iceland). Hence, it is unlikely that the present-day combination of climatic and non-climatic conditions prevailing in an analogue region today would be a physically plausible scenarios for conditions in the study region in the future, hence violating criterion 2.

Summary - analogue scenarios: The main flaw of scenarios that portray future climate by analogy with climate from the past or from another region lies in the causes of the analogue climate. These are almost certainly different from the causes underlying future, greenhouse gas induced climate change. However, these scenarios have the advantage of representing conditions that have actually been observed and experienced, rather than conditions hypothesised by models or expert judgement.